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Summary Report of Mission Acceleration Measurements for STS–60, SPACEHAB–2

Launched February 11, 1994

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ABSTRACT

The STS-60 mission, which launched on 11 February 1994, carried seven accelerometer systems. This report describes the configuration of each of these systems, where they were located on the Orbiter and the name of a contact person for each system. The Space Acceleration Measurement System (SAMS) was one of the accelerometer systems on-board and this mission marked its eighth successful flight. Acceleration data are provided here for SAMS which flew under an agreement between the NASA Microgravity Science and Applications Division and the NASA Office of Advanced Concepts and Technology. Acceleration data for the other accelerometer systems are not presented here.

SAMS was located in the commercial SPACEHAB laboratory, on its second flight. The SAMS system was configured with three triaxial sensor heads with filter cut-offs of 5, 10 and 50 Hz. The acceleration environment related to an experiment centrifuge, an experiment refrigerator freezer unit, a SAMS sensor head rotation, an Orbiter shudder, and payload deploy activities are discussed. In the Appendices, all of the data from SAMS Head B (10 Hz) are plotted to provide an overview of the environment during the majority of the STS-60 mission.

An evaluation form is included at the end of the report to solicit users' comments about the usefulness of this series of reports.

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ACRONYM LIST

3-DMA	Three-dimensional Microgravity Accelerometer
BREMSAT	University of Bremen Satellite
CMDS	Consortium for Materials Development in Space
CMMR	Center for Microgravity and Materials Research
DSO	Detailed Supplementary Objective
DTO	Development Test Objective
GAS	Get Away Special
GMT	Greenwich Mean Time (day/hour:minute:second)
GSFC	NASA Goddard Space Flight Center
JSC	NASA Johnson Space Center
KSC	NASA Kennedy Space Center
LeRC	NASA Lewis Research Center
MET	Mission Elapsed Time (day/hour:minute:second)
MMD	Microgravity Measuring Device
MSAD	Microgravity Science and Applications Division
OACT	NASA Office of Advanced Concepts and Technology
OSE	Orbiter Stability Experiment
PAS	Passive Accelerometer System
PBE	Pool Boiling Experiment
PIMS	Principal Investigator Microgravity Services
RCS	Reaction Control System
RMS	Orbiter Remote Manipulator System
rms	root mean square
SAMS	Space Acceleration Measurement System
SOR/F	Stirling Orbiter Refrigerator Freezer
SVEC	Space Vacuum Epitaxy Center
UAH	University of Alabama in Huntsville
UH	University of Houston
VRCS	Vernier Reaction Control System
WSF	Wake Shield Facility
X_A, Y_A, Z_A	SAMS sensor head A axes
X_B, Y_B, Z_B	SAMS sensor head B axes
X_C, Y_C, Z_C	SAMS sensor head C axes
X_0, Y_0, Z_0	Orbiter structural coordinate system axes

1. INTRODUCTION AND PURPOSE

Fluid physics, materials sciences, and life sciences experiments are conducted on the NASA Space Shuttle Orbiters because of the reduced gravity environment resulting from the continuous free fall state of low earth orbit. While being in orbit does result in zero-gravity at the center of mass of the Orbiter, at any point off of the center of mass some residual acceleration exists. These "quasi-steady accelerations" are related to the distance from the Orbiter center of mass, the aerodynamic drag experienced by the Orbiter but not by free floating objects or fluids within the Orbiter, and the effects of the rotation of the Orbiter. Accelerometer systems are flown on the Orbiters to record levels of such residual acceleration as well as vibrations of the Orbiter and local structures, commonly referred to as g-jitter. The quasi-steady and g-jitter environment of the Orbiter are collectively referred to as the microgravity or low-gravity environment.

The Wake Shield Facility (WSF) and SPACEHAB laboratory flew on the STS-60 mission in February 1994. Several microgravity experiments were flown on these carriers. To support the SPACEHAB experiments, an accelerometer system managed by the NASA Lewis Research Center (LeRC) was flown. The Space Acceleration Measurement Systems (SAMS) is sponsored by the Microgravity Science and Applications Division (MSAD) of the NASA Office of Life and Microgravity Science and Applications. Six other accelerometer systems were also aboard to support various experiments.

The Principal Investigator Microgravity Services (PIMS) project at the NASA Lewis Research Center supports principal investigators of microgravity experiments as they evaluate the effects of varying acceleration levels on their experiments. This report is provided by PIMS to furnish interested experiment investigators with a guide to evaluating the acceleration environment during STS-60 and as a means of identifying areas which require further study. To achieve this purpose, we present various pieces of information. Section 2 of this report provides an overview of the STS-60 mission: the payloads and the experiments manifested on the payloads. Section 3 describes the accelerometer systems flown on STS-60 and provides a list of contact names for the different systems. Section 4 discusses some specific analysis of the SAMS accelerometer data in relation to the various activities which occurred during the mission. The appendices outline processing applied to the SAMS data to provide an overview of the microgravity environment during the entire mission. Plots resulting from this analysis are also provided as a snapshot of the environment. Appendix D contains a user comment sheet. Users are encouraged to complete this form and return it to the authors.

2. MISSION OVERVIEW

At 7:10 am EST, 3 February 1994, the Space Shuttle Discovery launched on the STS-60 mission from NASA Kennedy Space Center (KSC). Touchdown at KSC was on 11 February 1994 at 2:19 pm EST. In terms of other time references, launch was at Greenwich Mean Time (GMT) 034/12:10 and Mission Elapsed Time (MET) 000/00:00 and landing was at GMT 042/19:19 and MET 008/07:09, where GMT and MET are given in day/hour:minute:second. The primary objectives of the STS-60 mission were the deployment and retrieval of the Wake Shield Facility and the operations of experiments in the SPACEHAB laboratory on its second mission (SPACEHAB-2). The STS-60 payload configuration is shown in Figure 1.

The Wake Shield Facility is a 12-foot diameter, stainless steel disk designed to be deployed and retrieved by the Orbiter Remote Manipulator System (RMS). While in free drift, the WSF is designed to generate an "ultra-vacuum" environment within which thin film materials can be grown. The principal objectives for the first flight of WSF were to characterize the environment generated by the WSF and the flow field around the WSF and to grow thin film gallium arsenide. The WSF consists of two main components: the Shuttle Cross Bay Carrier and the Free Flyer. The WSF experiments are listed in Table 1.

The SPACEHAB laboratory is a commercially developed pressurized facility designed to double the existing Orbiter habitation volume and quadruple crew-tended space experiment volume. On STS-60 the SPACEHAB-2 laboratory was located in the forward end of the cargo bay and was accessed from the Orbiter middeck through a tunnel. The SPACEHAB-2 payload layout and an external view of the SPACEHAB laboratory are shown in Figures 2 and 3, respectively. The SPACEHAB-2 experiments are listed in Table 2.

Secondary objectives of the mission were the activation and command of the Capillary Pumped Loop/GAS bridge experiments, Orbital Debris Radar Calibration Spheres, and the Bremen Satellite Experiment (BREMSAT). These experiments, and the middeck experiments flown on STS-60 are listed in Table 3. The fourteen development test objectives (DTO), and ten detailed supplementary objectives (DSO) are listed in Table 4.

3. STS-60 ACCELEROMETER SYSTEMS

Seven accelerometer systems flew on STS-60 to characterize different aspects of the Orbiter acceleration/vibration environment: the Bremen Satellite accelerometers, the Microgravity Measuring Device (MMD), the Orbiter Stability Experiment (OSE), the Passive Accelerometer System (PAS), the Pool Boiling Experiment (PBE) accelerometer, the Space Acceleration Measurement System, and the Three-dimensional Microgravity Accelerometer (3-DMA).

The following paragraphs describe each of these accelerometer systems with the exception of the BREMSAT accelerometer. Information on that system was not available at the time that this publication was released. Table 5 provides a list of people responsible for each of the systems.

3.1 Microgravity Measuring Device

The Microgravity Measuring Device was flown on STS-60 to characterize the microgravity environment of the WSF Free Flyer and the WSF carrier. An additional aspect of the MMD flight was an analysis of the response of the WSF to thruster impingement. MMD was sponsored by the Space Vacuum Epitaxy Center of the University of Houston in support of the NASA JSC. Four MMD units flew on the WSF, one on the Shuttle Cross Bay Carrier and three on the Free Flyer. Data were recorded at 25 samples per second for each of three axes on each unit. The MMD data are currently being analyzed by MMD personnel and a preliminary report is available [1].

3.2 Orbiter Stability Experiment

The NASA GSFC Orbiter Stability Experiment is designed to measure the vibration environment of the Orbiter in support of fine-pointed optical instruments which require line of sight stability. The OSE measures angular accelerations of the Orbiter with respect to the sun while the Orbiter is oriented in a solar intertial attitude with the payload bay pointed at the center of the sun. These accelerations are measured using sun sensors with an angular sensitivity of 0.1 arc-sec. With this sensitivity, OSE is expected to detect Orbiter body motions above 1 Hz, possibly seeing the Orbiter structural resonances below 5 Hz. Analog signals from the sensors were passed through an 11 Hz lowpass filter with 12 dB/octave rolloff, amplified, and sampled at 58 samples per second [2]. OSE was activated at MET 007/02:59 and turned off at MET 007/03:48. The 45 minutes worth of data collected are currently bring analyzed by OSE personnel.

3.3 Passive Accelerometer System

The Passive Accelerometer System was flown on STS-60 in conjunction with the 3-DMA. PAS was developed at the Center for Microgravity and Materials Research at the University of Alabama in Huntsville to estimate the magnitude of quasi-steady accelerations related to atmospheric drag and gravity gradient effects. PAS operations are based on a simple method used to measure viscosity. The instrument is comprised of a spherical steel mass in a tube filled with a fluid of known viscosity. The time it takes the mass to drift along a known distance in the fluid is used to calculate the velocity of the mass, and from that the acceleration is calculated

4]. Due to the increased demand on crew time required for WSF activities, the number of planned PAS measurements was decreased. One good reading was obtained but, due to excessive Orbiter maneuvering to maintain a defined attitude, the result is inconclusive [5].

3.4 Pool Boiling Experiment Accelerometer

A triaxial accelerometer system was included on the Pool Boiling Experiment, GAS experiment G-536. The sensor head incorporated into PBE is a SAMS-style triaxial sensor head. The PBE-specific acquisition system is designed to record data at a sample rate of 10 samples per second during each PBE experiment run. A lowpass second order Butterworth filter is applied to the data so that the 3 dB (1/2 power) point is at 2.5 Hz. The PBE accelerometer data are currently being analyzed by the PBE project team.

3.5 Space Acceleration Measurement System

STS-60 marked the eighth successful flight of the SAMS system. SAMS was developed to monitor and measure the low-gravity environment of Orbiters in support of MSAD-sponsored science payloads [2, 6-8]. SAMS flew on STS-60 under an agreement between MSAD and the NASA Office of Advanced Concepts and Technology (OACT) in support of the OACT sponsored SPACEHAB-2 experiments. SAMS consists of three remote triaxial sensor heads, connecting cables, and a controlling data acquisition unit with a digital data recording system using optical disks with 200 megabytes of storage capacity per side. Lowpass filters were applied to the data with cutoffs at 5, 50, and 100 Hz. Data were then sampled and recorded at 25, 250, and 500 samples per second, respectively. The locations and orientations of the SAMS heads, with respect to the Orbiter structural coordinate system, are given in Table 6. The Orbiter structural coordinate system is shown in Figure 4. More detailed descriptions of the SAMS accelerometers are available in the literature [6-9].

On STS-60, SAMS data recording started at MET 000/08:35 and ended at 007/23:38. Due to increased demand on crew time required for WSF activity, two SAMS disk changes were missed. As a result, about 26 minutes of data between 005/10:50:29 and 005/11:16:52 were lost. Approximately 3.67 gigabytes of SAMS data were collected over 168 hours of recording. Appendix A describes how SAMS data can be accessed via the internet.

3.6 Three-dimensional Microgravity Accelerometer

The Three-dimensional Microgravity Accelerometer was developed at the Consortium for Materials Development in Space at the University of Alabama in Huntsville. The 3-DMA had four accelerometer units located in the SPACEHAB laboratory: three remote triaxial sensors and one sensor composed of three single axis invertible accelerometers. The system was configured so that data sampling could be switched between 52.08 and 99 samples per second. The sampling rate was switched to the higher rate about two-thirds of the way through the mission when it was determined that sufficient disk space was available to record at that rate for the remainder of the mission. Approximately 6 gigabytes of data were recorded on three magnetic hard drive devices. For each remote sensor, data were recorded at three gain levels: a coarse channel with range ±12 g, a medium channel with range ±0.01 g, and a fine channel with range ±0.001 g. The 3-DMA data are currently being analyzed by 3-DMA personnel and are available from the contact person listed in Table 5.

4. ORBITER MICROGRAVITY ENVIRONMENT

The acceleration environment measured by an accelerometer system on the Orbiter is contributed to by numerous sources. All ongoing operations of crew life support systems and activities and operations of the Orbiter, crew, carrier, and experiments tend to have vibratory and/or oscillatory components that contribute to the "background" acceleration environment. In this report we are concerned with the identification of activities that cause acceleration levels above this background. The Appendices provide an overview of the low-gravity environment during the STS-60 mission. Appendix B shows time history plots of SAMS data. Except where noted, all SAMS data plots shown in this document are from SAMS Head B. Appendix C provides a frequency domain representation of the SAMS data.

On the STS-60 mission, some of the activities which had an impact on the acceleration environment were: crew sleep, nominal crew activity, crew exercise, DSO 202 centrifuge activity, use of the RMS, WSF deploy activities, BREMSAT deploy activities, and Orbiter attitude maneuvers. The acceleration levels related to crew sleep, nominal crew activity, and Orbiter vernier and primary reaction control system firings are discussed in the literature and will not be discussed here [2-4, 6-10]. Due to increased crew involvement in WSF activities, crew exercise times were not consistently catalogued. Evaluation of the vibration environment related to the isolation system used will be performed after its second flight on STS-62 [11].

Our primary focus in this section will be the characterization of the acceleration environment during the following activities: DSO 202 centrifuge activity, Stirling Orbiter Refrigerator Freezer activity, SAMS sensor head rotation, crew report of an Orbiter "shudder," and BREMSAT deploy activities. Fig. 5a is a time history of SAMS Head B data for a reference time period during which nominal crew activity was occurring. Fig. 5b shows the power spectral density representation of the data. These plots can be used as a baseline against which to compare the data presented for the activities of interest. Of note in the power spectral density plots are the 17, 34, and 51 Hz modes related to the Ku band antenna and a 60 Hz mode related to a refrigerator freezer discussed in 4.2.

4.1 DSO 202 Centrifuge Activity

DSO 202 was a joint U.S.-Russia metabolic investigation into the effect of microgravity on body fluids. This investigation involved processing of samples using a centrifuge in the SPACEHAB laboratory. During several runs, the crew attached the centrifuge to the SPACEHAB floor using suction cups, causing vibrations noticeable by the crew. To avoid experiment disruptions, later centrifuge runs were performed with the centrifuge "free-floating" in the SPACEHAB. During these runs, the centrifuge was attached to the SPACEHAB structure with a strap. Fig. 6a is a time history of SAMS Head B data for approximately one minute starting at MET 000/20:46:00 while the centrifuge was attached to the floor. Fig. 6b shows the power spectral density representation of the data. Note that in addition to Orbiter structural modes present below 10 Hz, a strong 16.5 Hz component is excited. This frequency appears to be related to the centrifuge activity. Fig. 7a is a time history of SAMS Head B data starting at MET 005/22:32:00 during a free-floating centrifuge run. Fig. 7b shows the power spectral density representation of the data. Note that the magnitude of the 16.5 Hz component in the X-axis is reduced by a factor of three while the magnitude of the Y- and Z-axis 16.5 Hz components stayed at the same levels. This indicates that the vibration isolation afforded by the strap system used was only successful in the X-axis.

4.2 Stirling Orbiter Refrigerator Freezer Activity

The Stirling Orbiter Refrigerator Freezer flew in the SPACEHAB Laboratory to test and characterize its operations in microgravity. The SOR/F used environmentally benign helium in its system and can be chilled quickly. Its capacity is variable and its motor is sealed within the fluid loop to prevent leaks. Evaluation of vibrations associated with the SOR/F on the ground by the 3-DMA instrument indicated a predominant 60 Hz frequency. This signal relates to the driving frequency of the piston type pump used in the SOR/F [12]. Initial analysis of the SAMS data from random times during STS-60 showed excitation at 60 Hz that was dominant over all other excited frequencies. Fig. 8a is a time history of SAMS Head B data during a randomly selected time starting at MET 002/04:50:00. Fig. 8b shows the power spectral density representation of the data. Note the strong 60 Hz signal. Note that a lowpass filter with a cutoff frequency of 50 Hz was applied to the Head B data before digitization. The signal level at 60 Hz shown in Fig. 8 is therefore reduced by about 11 dB.

4.3 SAMS Head Rotation

The signal recorded by the SAMS units is a combination of actual acceleration levels and instrument factors. Each SAMS sensor outputs a voltage level which includes a signal indicative of the applied acceleration and a signal indicative of the sensor bias. Compensation of data for bias is typically performed after landing using coefficients obtained from measurements performed on Earth. Several errors arise during this process, many because of the difference between the one-g environment in which sensor calibrations are performed and the microgravity environment in which the measurements are taken [13].

A simple procedure was performed during the STS-60 mission to improve the current SAMS measurement process by reducing bias error and characterizing the accuracy of the measurements. At MET 006/00:56, SAMS TSH-C was rotated 180° about its X-axis for a period of ten minutes and then rotated back to its original orientation for the remainder of the mission. Data were recorded throughout the procedure. By reversing the sensor, the acceleration signal is reversed in polarity, but the bias signal is not. Taking measurements before and after the reversal of the sensor allows the bias to be calculated and (theoretically) removed by post-mission data processing. Fig. 9a is a time history of SAMS Head C data showing the initial rotation of the head. At about forty seconds into the plot, note the transient net acceleration change in the Y- and Z-axis data during the rotation about the X-axis. Fig. 9b shows the power spectral density representation of the data. These plots are provided here to show the effect of this procedure on the data collected during the rotation. Details of the bias compensation analysis are given in [13].

4.4 Orbiter Shudder

During the STS-60 mission, the crew heard a noise coming from the aft of the Orbiter that sounded like a Primary Reaction Control System jet firing. At that time, the Reaction Control System (RCS) was in a mode to fire only the Vernier RCS (VRCS) engines. An initial explanation of the "shudder" was that it was the result of the Orbiter and SPACEHAB (or other cargo) adapting to large temperature differences resulting from the sun/shade variations. Investigation by JSC propulsion teams after the flight indicated that three VRCS engines fired simultaneously, creating the shudder. Fig. 10a is a time history of SAMS Head C data starting at MET 007/03:43:05. Note the large magnitude transient approximately three seconds into the plot. Fig. 10b shows the power spectral density representation of the data. According to data obtained from the NASA JSC Mission Evaluation Workstation System there is no record of three simultaneous VRCS engine firings at the time of the peak in the SAMS data (MET 007/03:46:05). Several occurrences of three simultaneous VRCS firings within six minutes of the event in question do not show any significant signature in the SAMS data. It is our conclusion, therefore, that the shudder felt and heard by the crew at this time was not related to a simultaneous firing of three VRCS engines. Other possible causes are under investigation.

4.5 BREMSAT Deploy Activities

The deploy of the Bremen Experiment Satellite was a secondary objective of the STS-60 mission. BREMSAT carries six scientific experiments, including accelerometers to study the microgravity conditions before deployment and while in orbit. BREMSAT was deployed from its GAS canister at about MET 006/07:13. The most significant impact the BREMSAT deploy had on the microgravity environment was caused by the maneuver away from the satellite beginning at about MET 006/07:16. SAMS Head C data collected during this series of engine firings are shown in Fig. 11. Note the large magnitude of these accelerations compared to previous plots.

5. Summary

This report serves as a road map to the SAMS data acquired during the STS-60 mission. Further analysis of specific events and comparisons with other missions will be performed and published in future documents.

There were two primary payloads for the STS-60 mission: the SPACEHAB-2 and the Wake Shield Facility. Seven accelerometer systems flew on this mission to support various experiments in different locations.

A mission summary of the vector magnitude RMS and average accelerations for the entire mission was produced for a SAMS 50 Hz triaxial sensor head. Spectrograms were also produced to give a frequency domain summary for the entire mission. These plots are presented in the Appendices. Significant events were chosen to give a more detailed look at the acceleration disturbances at the SAMS head locations. These events are DSO 202 Centrifuge operations, Stirling Orbiter Refrigerator Freezer operations, SAMS TSH-C rotation, an Orbiter shudder felt by the crew, and the deploy of the BREMSAT satellite.

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Table 1 WAKE SHIELD FACILITY EXPERIMENTS

FACILITY	SPONSOR
Charging Hazards and Wake Shield	Space Vacuum Epitaxy Center (SVEC), University of Houston (UH)
Containerless Coating Process	US Army Construction Engineering Research Laboratory
Materials Laboratory -1	Center for Materials for Space Structure, Case Western Reserve University
Microgravity Measuring Device	SVEC, UH
Plume Impingement Experiment	SVEC, UH

Table 2 SPACEHAB-2 EXPERIMENTS

EXPERIMENT	TECHNICAL CONTACT
Materials Processing experiments	
Equipment for Controlled Liquid-Phase Sintering Experiments (ECLiPSE)	Dr. J. E. Smith, Jr., University of Alabama in Huntsville (UAH)
Space Experiment Facility	Dr. J. E. Smith, Jr., UAH
Life Sciences Experiments	
ASTROCULTURE	Dr. R. J. Bula, Wisconsin Center for Space Automation and Robotics , University of Wisconsin
Bioserve Pilot Laboratory	Dr. L. Stodieck, University of Colorado (UC)
Commercial Generic Bioprocessing Apparatus	Dr. M. Robinson, UC
Commercial Protein Crystal Growth	B. Adams
IMMUNE-01	Dr. R. Zimmerman, Chiron Corp.
Organic Separation	Dr. R. J. Naumann, UAH
Penn State Biomodule	Dr. Z. Smilowitz and Dr. W. McCarthy, Penn State University
Microgravity Measurements	
Space Acceleration Measurement System	R. Sicker
Three-Dimensional Microgravity Accelerometer	J. Bijvoet, UAH
Passive Accelerometer System	J.I.D. Alexander, UAH
Other Activities	
Sample Return Experiment	Dr. P. Tsore, Jet Propulsion Laboratory
Stirling Orbiter Refrigerator Freezer	

Table 3 ADDITIONAL STS-60 EXPERIMENTS

EXPERIMENT NAME	TECHNICAL CONTACT
GAS-536 Pool Boiling Experiment	Angel Otero, NASA LeRC
GAS-557 Capillary Pumped Loop Experiment	R. Hoffman, NASA GSFC
GAS-071 Orbiter Ball Bearing Experiment	D. Peters, NASA GSFC
GAS-514 Orbiter Stability Experiment	Werner Neupert, NASA GSFC
University of Bremen Satellite	University of Bremen, Applied Space Technology and Microgravity
Orbital Debris Radar Calibration Spheres	Solar System Exploration Division, NASA JSC
Auroral Photography Experiment B	U.S. Air Force
Shuttle Amateur Radio Experiment	NASA JSC Amateur Radio Club

Table 4 STS-60 Development Test Objectives Detailed Supplementary Objectives

DTOs / DSOs	Description
DTO 301D	Ascent structural capability evaluation
DTO 305D	Ascent compartment venting evaluation
DTO 306D	Entry compartment venting evaluation
DTO 307D	Entry structural capability evaluation
DTO 312	ET TPS performance (method 3)
DTO 319D	Shuttle/payload low-frequency environment
DTO 414	APU shutdown test, sequence B (shutdown 2, then 3, then 1)
DTO 623	Cabin air monitoring
DTO 656	PGSC single-event upset monitoring
DTO 664	Cabin temperature survey
DTO 670	Evaluation of passive cycle isolation system
DTO 700-2	Laser range and range rate device
DTO 700-7	Orbiter data for real-time navigation evaluation
DTO 805	Crosswind landing performance
DSO 200	Joint U.S.-Russian investigation: radiobiological effects
DSO 201	Joint U.S.-Russian investigation: sensory-motor investigations
DSO 202	Joint U.S.-Russian investigation: metabolic
DSO 204	Joint U.S.-Russian investigation: visual observations from space
DSO 325	Dried blood method for in-flight storage (protocol 1)
DSO 326	Window impact observations
DSO 487	Immunological assessment of crew members
DSO 901	Documentary television
DSO 902	Documentary motion picture photography
DSO 903	Documentary still photography

Table 5 STS-60 Accelerometer Systems

ACCELEROMETER SYSTEM	CONTACT PERSON
BREMSAT Accelerometers	not available
Microgravity Measuring Device	Michael Cooke, NASA JSC
Orbiter Stability Experiment	Werner Neupert, NASA GSFC
Passive Accelerometer System	J. Iwan D. Alexander, CMMR UAH
Pooling Boiling Experiment Accelerometer	Angel Otero, NASA LeRC
Space Acceleration Measurement System	Ron Sicker, NASA LeRC
Three-Dimensional Microgravity Accelerometer	Jan Bijvoet, CMDS UAH

Table 6 SAMS TSH Parameters for SPACEHAB-2

TSH A		
Serial no.: 821-6		Sample Rate: 500 samples/second
Frequency: 0 to 100 Hz		Location: Forward Bulkhead, Port T-beam
ORIENTATION		**LOCATION**
Orbiter Structural Axis	**Sensor Axis**	**Structural Coord. System**
X_O	$-X_A$	$X_O = 702.3$ in
Y_O	Y_A	$Y_O = -53.5$ in
Z_O	$-Z_A$	$Z_O = 392.1$ in

TSH B		
Serial no.: 821-9		Sample Rate: 250 samples/second
Frequency: 0 to 50 Hz		Location: Forward bulkhead, Starboard T-beam
ORIENTATION		**LOCATION**
Orbital Structural Axis	**Sensor Axis**	**Structural Coord. System**
X_O	$-X_B$	$X_O = 702.3$ in
Y_O	$-Y_B$	$Y_O = 53.5$ in
Z_O	Z_B	$Z_O = 391.7$ in

TSH C		
Serial no.: 821-1		Sample Rate: 25 samples/second
Frequency: 0 to 5 Hz		Location: Locker door FC01
ORIENTATION		**LOCATION**
Orbital Structural Axis	**Sensor Axis**	**Structural Coord. System**
X_O	$-X_C$	$X_O = 723.1$ in
Y_O	$-Y_C$	$Y_O = -19.1$ in
Z_O	Z_C	$Z_O = 436.6$ in

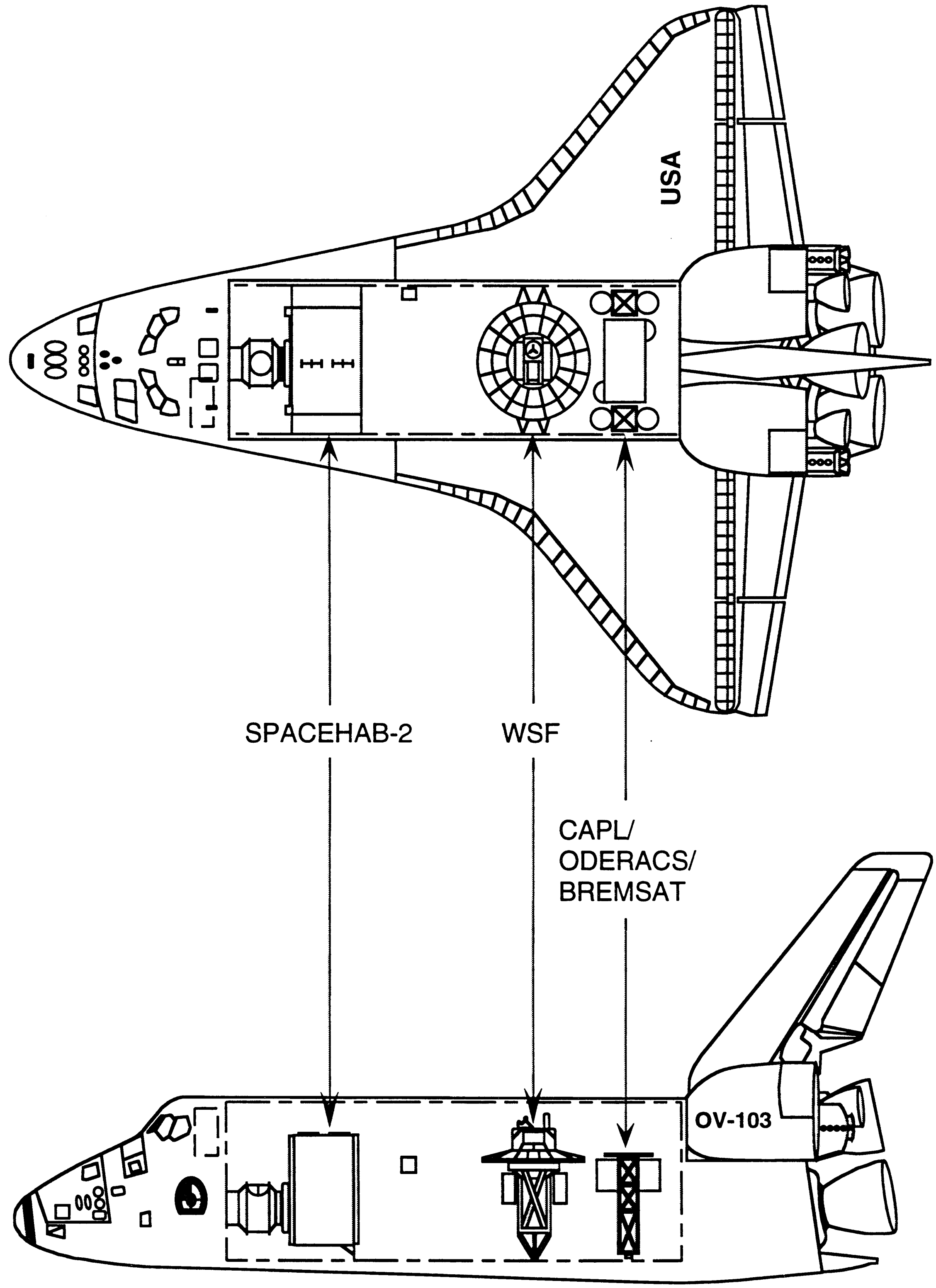


Fig. 1 STS-60 Payload Configuration

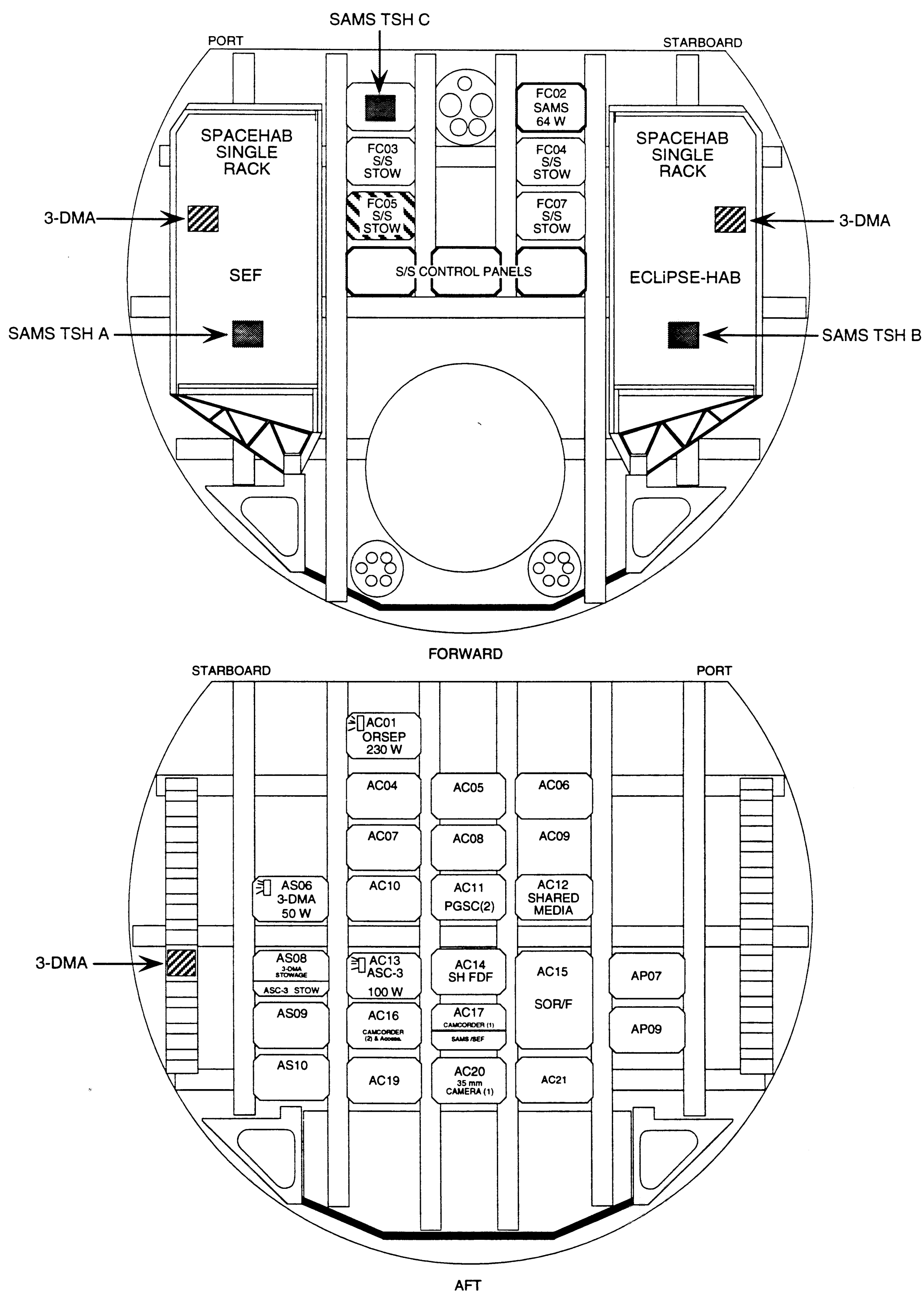


Fig. 2 SPACEHAB-2 Payload Layout

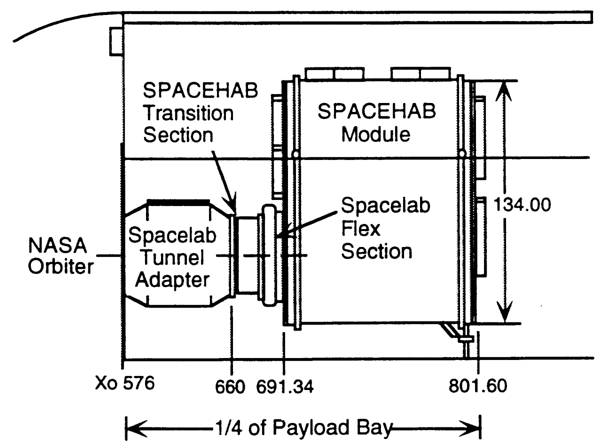
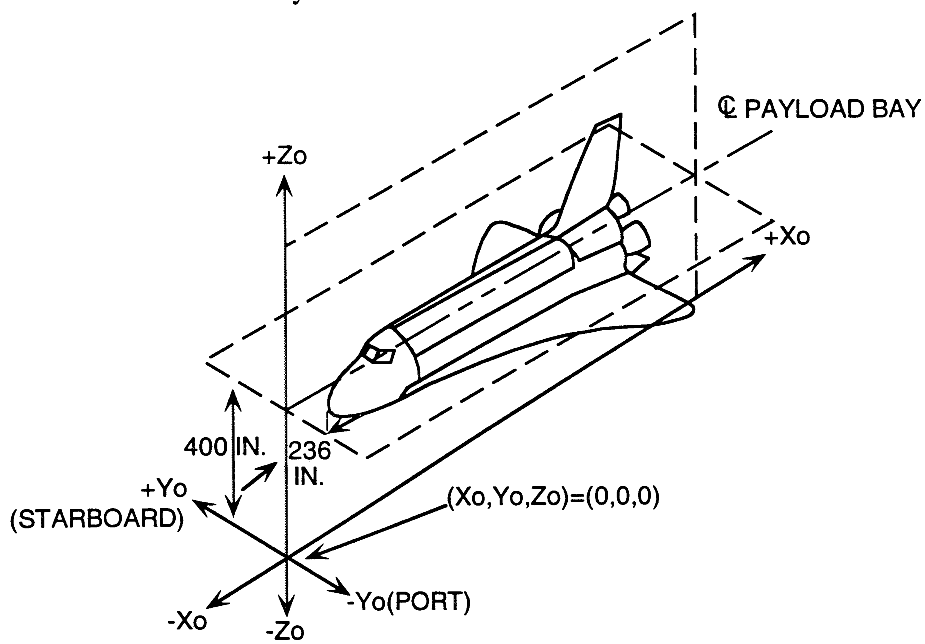


Fig. 3 SPACEHAB-2 external view, coordinates given in inches with respect to Orbiter structural coordinate system



ORIGIN: In the Orbiter plane of symmetry, 400 inches below the centerline of the payload bay and at the Orbiter X station = 0.

ORIENTATION: The X_0 axis is the vehicle plane of symmetry, parallel to and 400 inches below the payload bay centerline. Positive sense is from the nose of the vehicle toward the tail.

The Z_0 axis is in the vehicle plane of symmetry, perpendicular to the X_0 axis, and positive upward in the landing attitude.

The Y_0 axis completes a right-handed system.

Fig. 4 Orbiter structural coordinate system

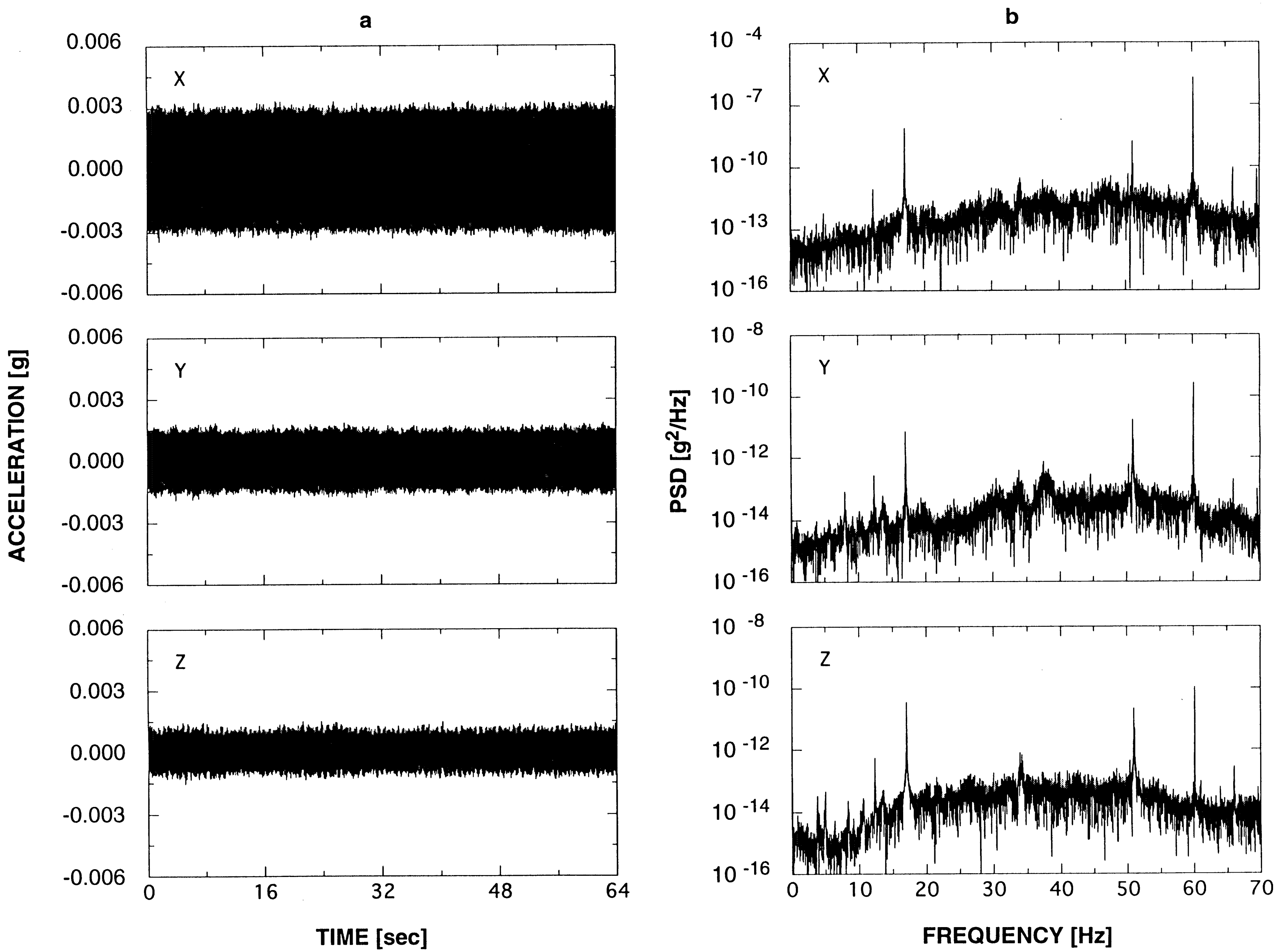


Fig. 5 SAMS Head B data for MET 001/15:00:05 to 001/15:01:09. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

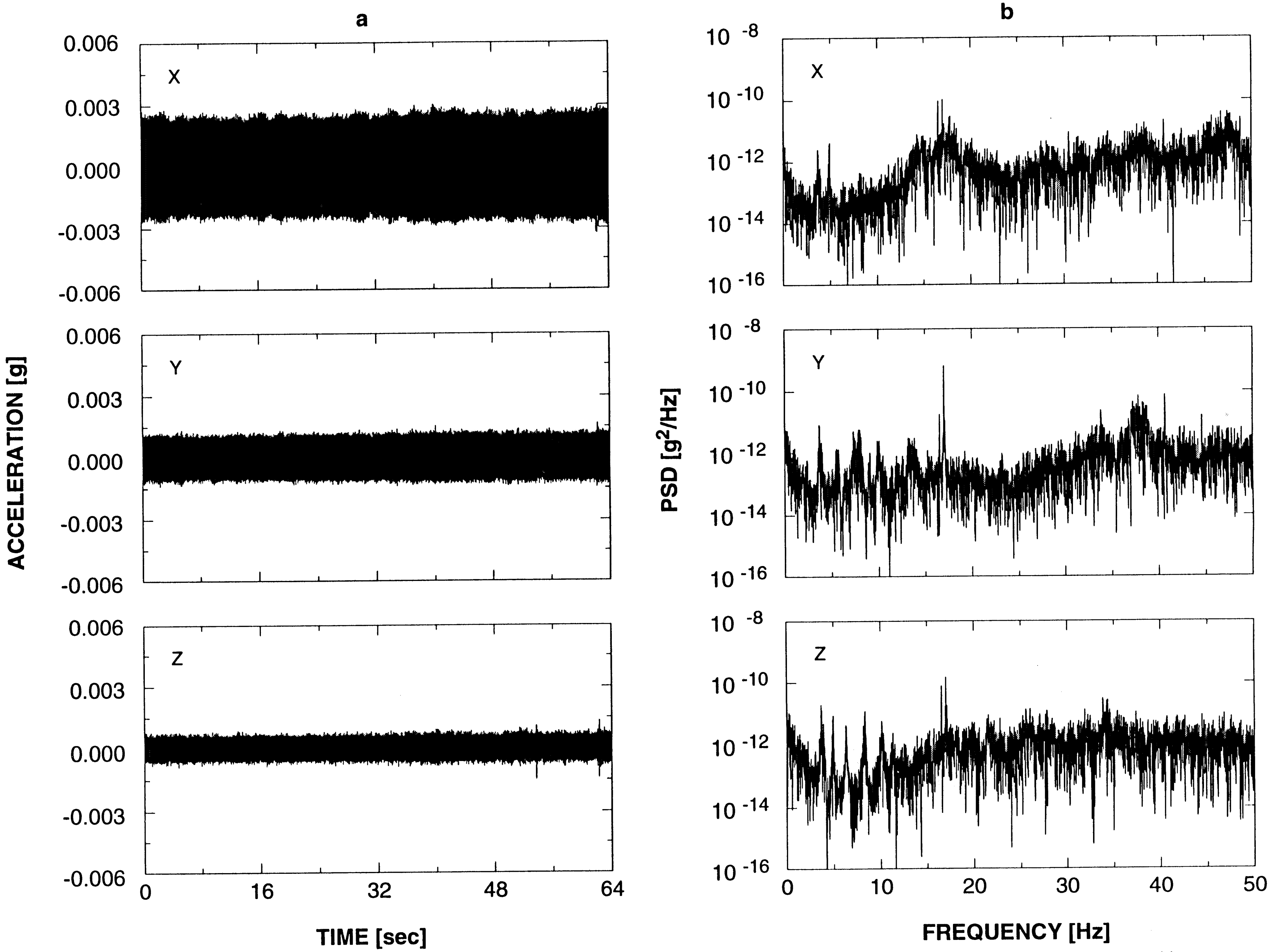


Fig. 6 SAMS Head B data for MET 000/20:46:00 to 000/20:47:04 during centrifuge operations. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

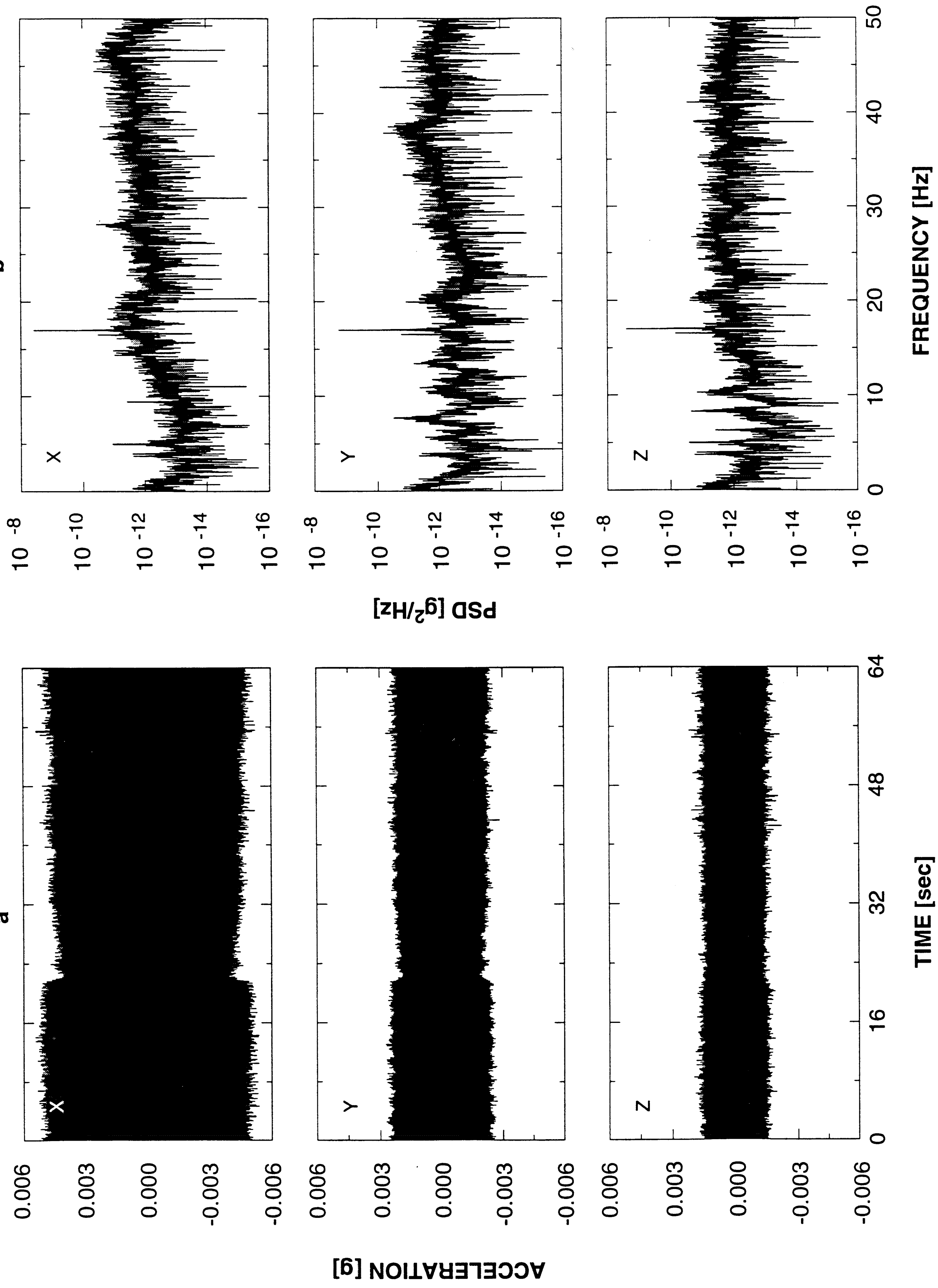


Fig. 7 SAMS Head B data for MET 005/22:32:00 to 005/22:33:04 during centrifuge operations. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

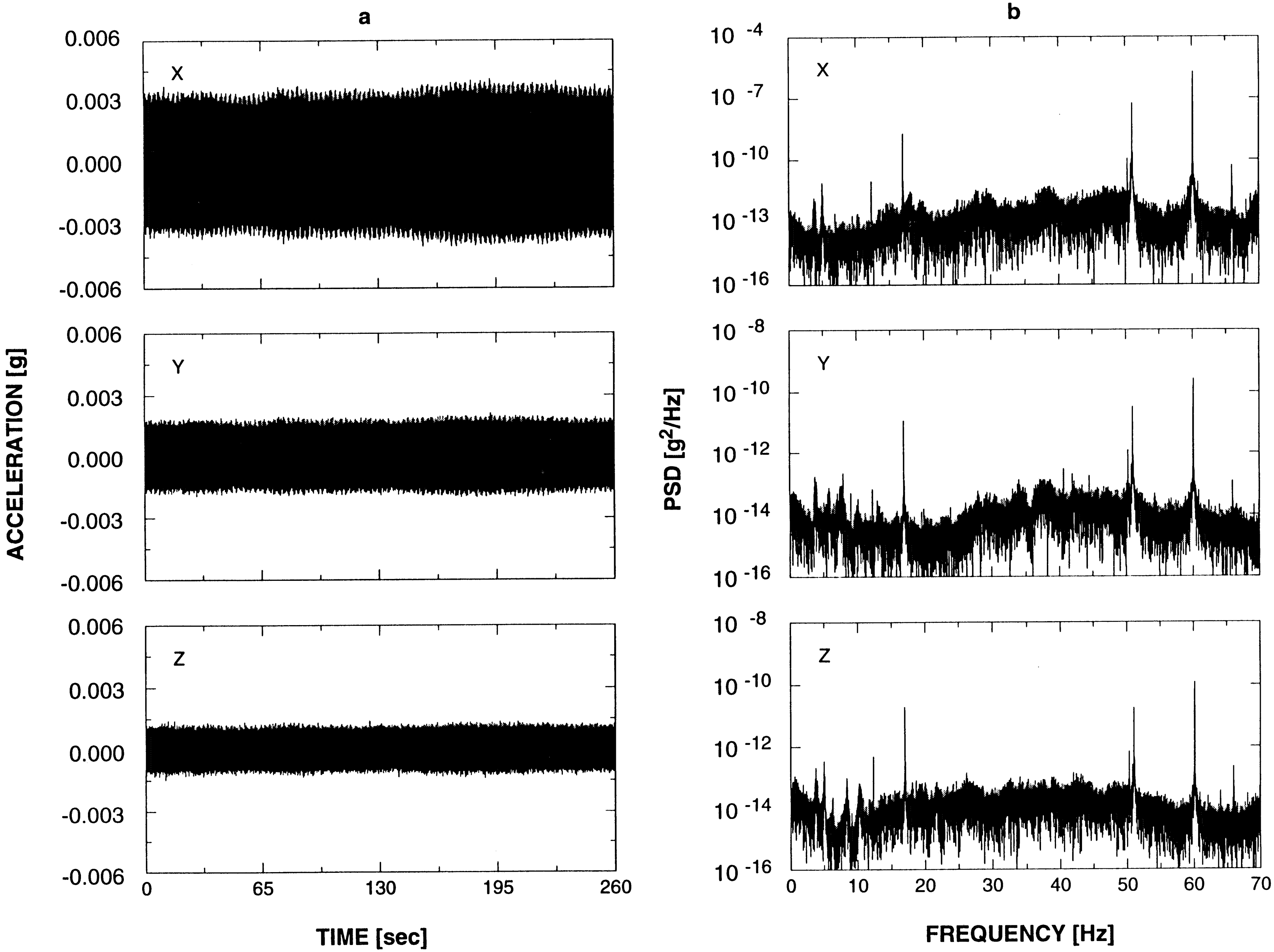


Fig. 8 SAMS Head B data for MET 002/04:50:00 to 002/04:54:20 showing the influence of the Stirling Orbiter Refrigerator Freezer. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

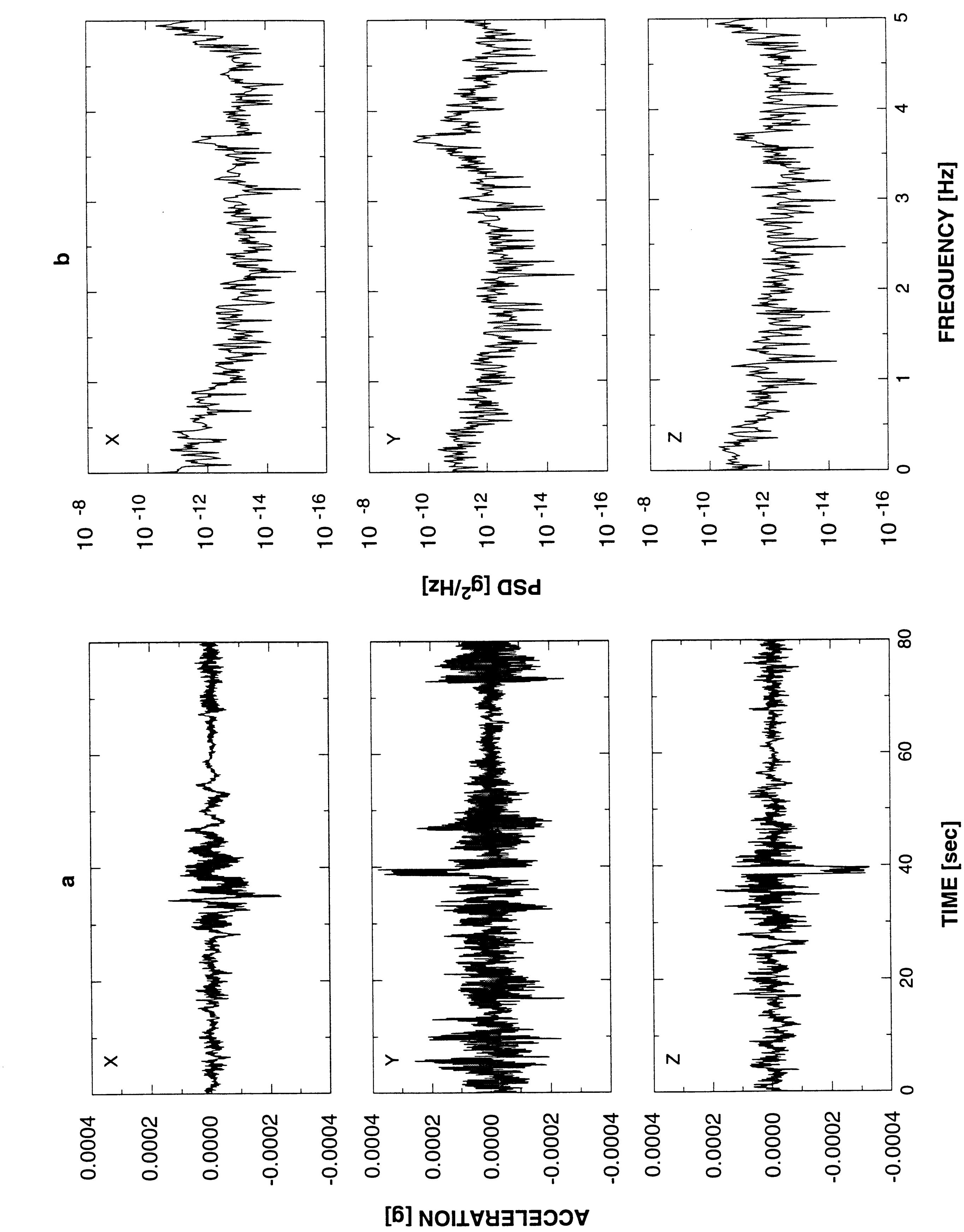


Fig. 9 SAMS Head C data for MET 006/00:55:30 to 006/00:56:50 during the sensor head rotation. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

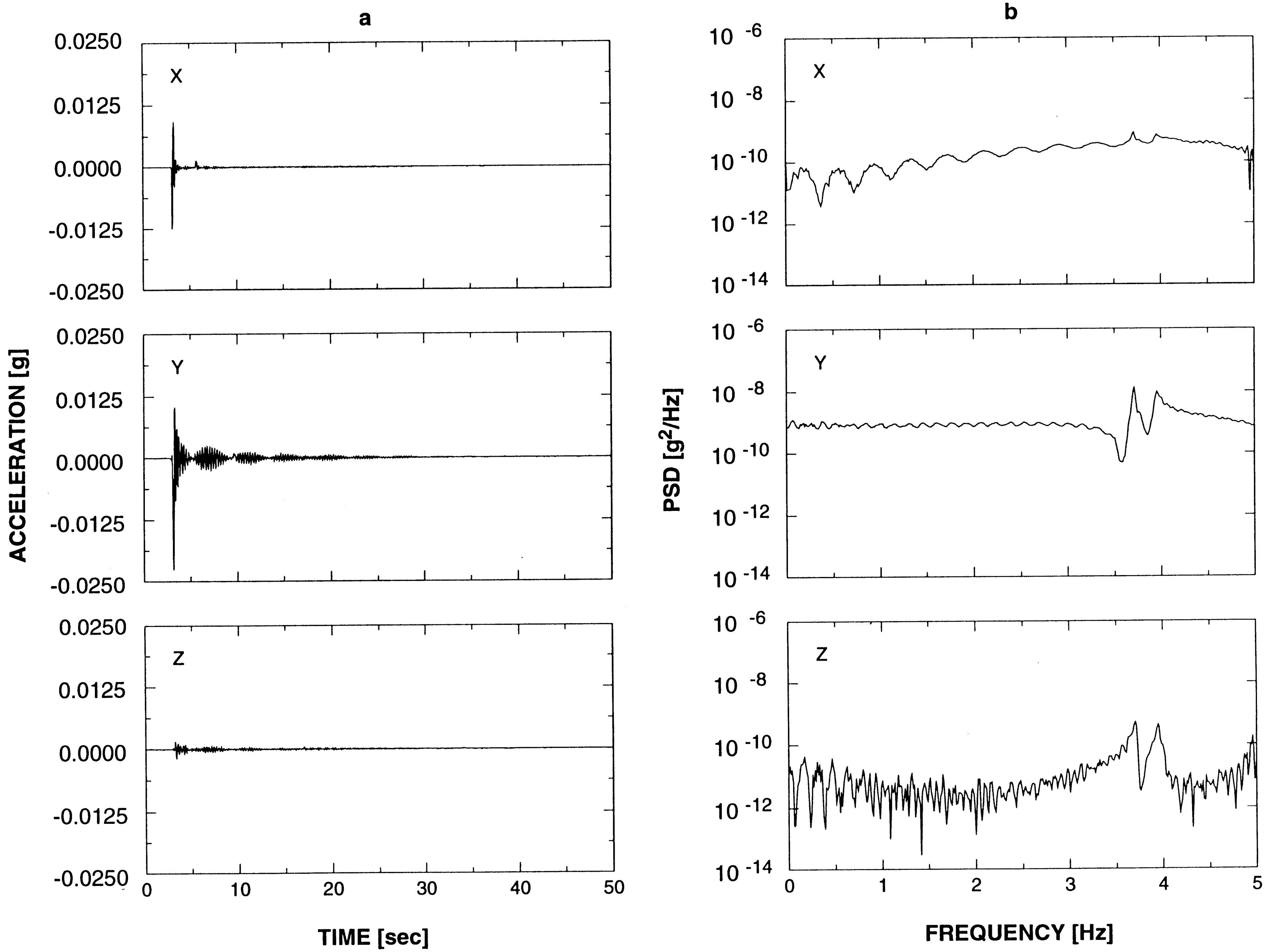


Fig. 10 SAMS Head C data for MET 007/03:43:50 to 007/03:44:40 during the time a shudder was felt by the STS-60 crew. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

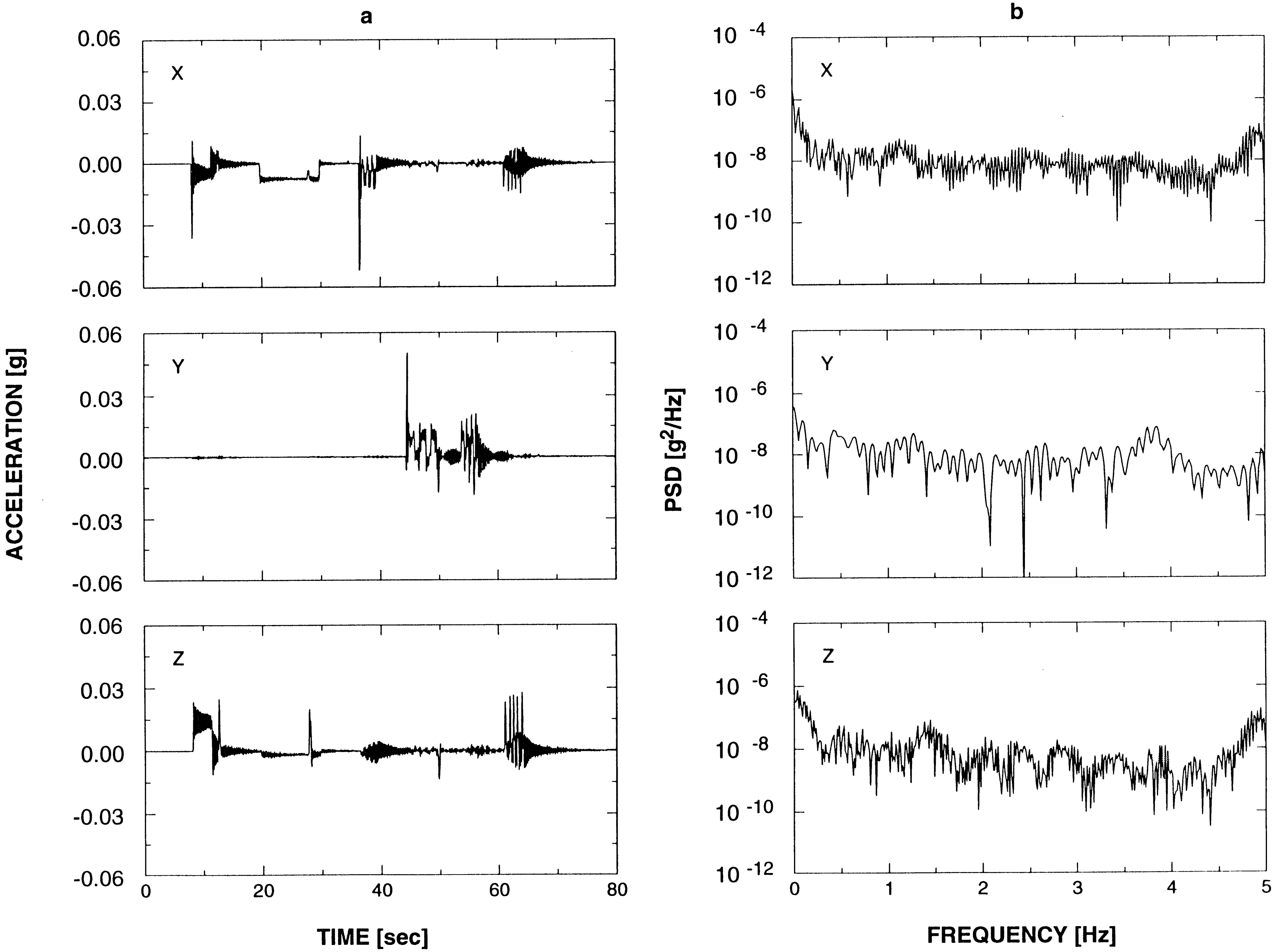


Fig. 11 SAMS Head C data for MET 006/07:16:10 to 006/07:17:30 during Discovery retreat after deploy of BREMSAT. a) Time history plots, b) power spectral density plots. Data in reference to Orbiter structural coordinate system.

APPENDIX A ACCESSING SAMS AND OARE DATA FILES

OARE and SAMS data files may be accessed from a file server at NASA LeRC. The NASA LeRC file server **beech.lerc.nasa.gov** (tcp/ip address 139.88.19.43) can be accessed via anonymous ftp, as follows

ftp 139.88.19.43
login anonymous
password guest
cd pub
ls (This will list files and directories under pub. OARE and SAMS data are organized within mission directories: usml1, usmp1, etc.)

The SAMS data files are organized in a tree-like structure as pictured in Figure A1. Files are broken down into categories based upon sensor head, mission day, and type of data. Files are stored at the lowest level in the tree, and the data file name reflects the contents of the file. For example, axm00102.15r contains data for sensor head a, the x axis, m means MET (if n, time has been converted into MET), day 001, hour 02, 1 of 5 files and r means reduced (temp/gain compensation applied). The file **readme.doc** provides a comprehensive description and guide to the data

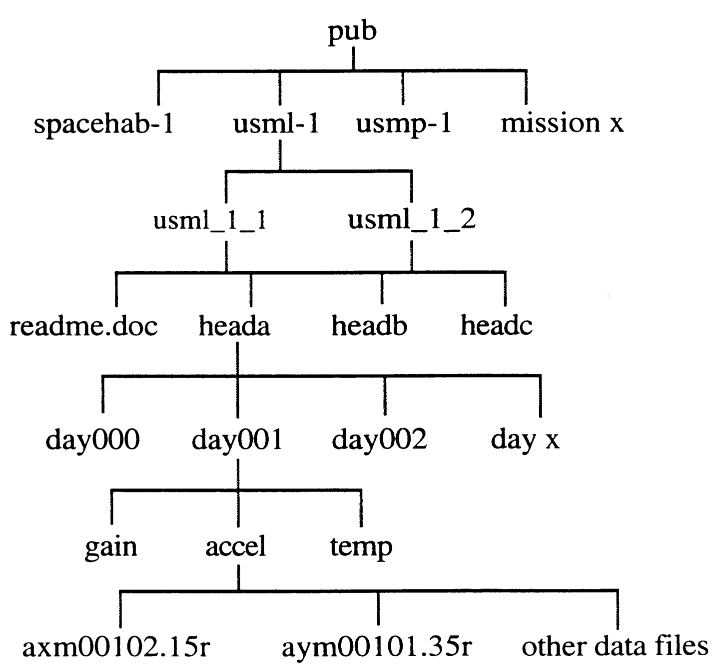


Figure A1 SAMS Data Directory Tree

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APPENDIX B SAMS TIME HISTORIES

Accelerometer data collected on Orbiter missions are generally analyzed by the PI or experiment team responsible for the system. For this reason, the contact person listed in the body of this report should be contacted with any specific questions about accelerometers and mission data. The PI Microgravity Services (PIMS) project at the NASA Lewis Research Center was formed in part to support microgravity PIs in the evaluation of acceleration effects on their experiments and to characterize the vibrational environment of the microgravity carriers and vehicles. The primary continual source of accelerometer data from mission to mission is SAMS. Some of the SAMS data from STS-60 are presented in Appendices B and C to provide PIs with an overview of the environment during the mission.

The raw data recorded by SAMS is processed to compensate for temperature and gain related errors of bias, scale factor, and axis misalignment. The processing utilizes a fourth order temperature model to compensate the data and convert the raw digitized data into engineering units [B1]. The data are transformed to the shuttle structural coordinate system and formatted into files for distribution via CD-ROM and file server. See Appendix A for information on file server access of SAMS data.

The compensated data are further processed to produce the plots included in Appendix B. Two time history representations of the data are provided: ten second average and ten second root mean square (rms) plots. These calculations are presented in two hour plots with the corresponding average and rms plots on one page. The ten second average plots should be used to identify times when the steady level of the acceleration signal deviates from the background level. The ten second rms plots should be used to identify times when oscillatory and/or transient deviations from the background acceleration levels occurred.

Average and Root Mean Square Calculations

The average plots were produced using STS-60 SAMS Head B data. Head B data were collected at 250 samples per second and a 50 Hz lowpass filter was applied to the data by the SAMS unit prior to digitization. The plots were produced by first forming the vector magnitude of the x, y, z axis data and then taking the average of consecutive ten second intervals of data. The average produces one data point for every ten seconds (N = 2500 points) of data. The following equation was used to calculate the ten second moving window average:

$$Average = \frac{1}{N}\sum_{j=1}^{N} V_j$$

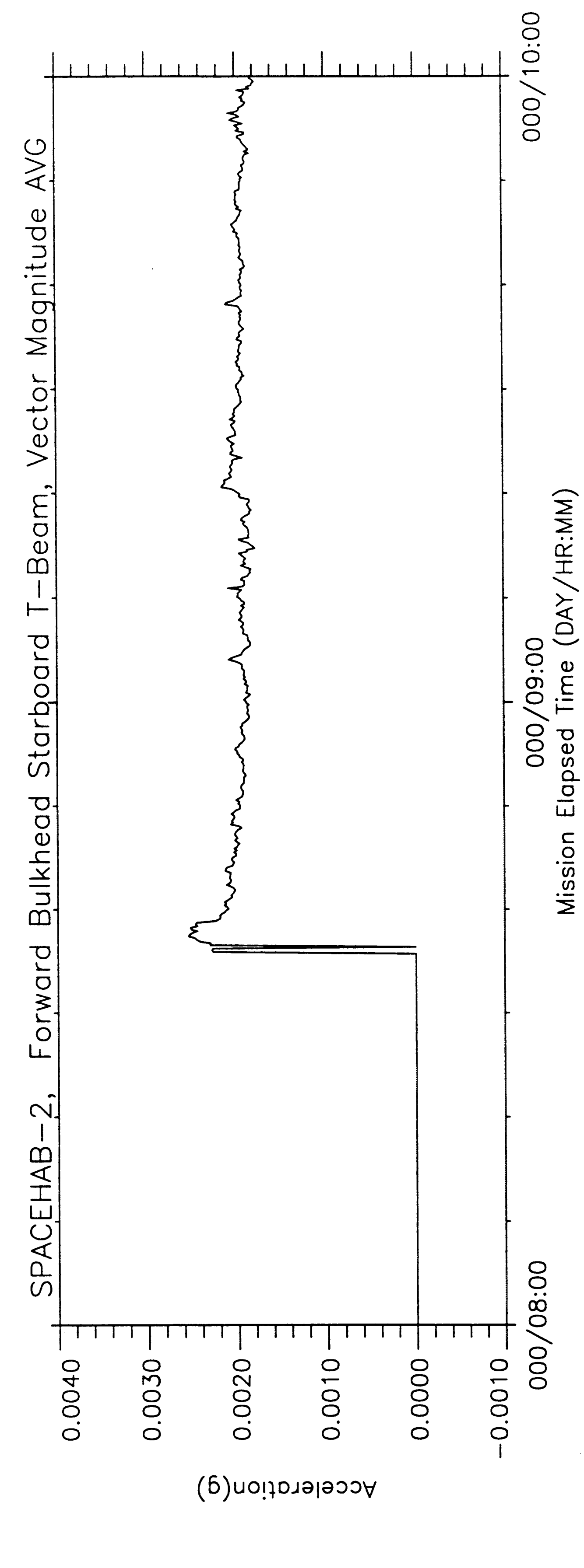
where V is the vector magnitude of the x, y, and z axis data.

The rms plots were produced by taking the rms of 10 second intervals for the two hour period. The root mean square of a discrete time series for 10 seconds was calculated using the following equation:

$$rms = \sqrt{\left(\frac{1}{N}\sum_{j=1}^{N} V_j^2\right)}$$

References

[B1] Thomas, J. E., R. B. Peters, B. D. , Finley, B. D. , Space Acceleration Measurement System triaxial head error budget, NASA TM-105300, January 1992.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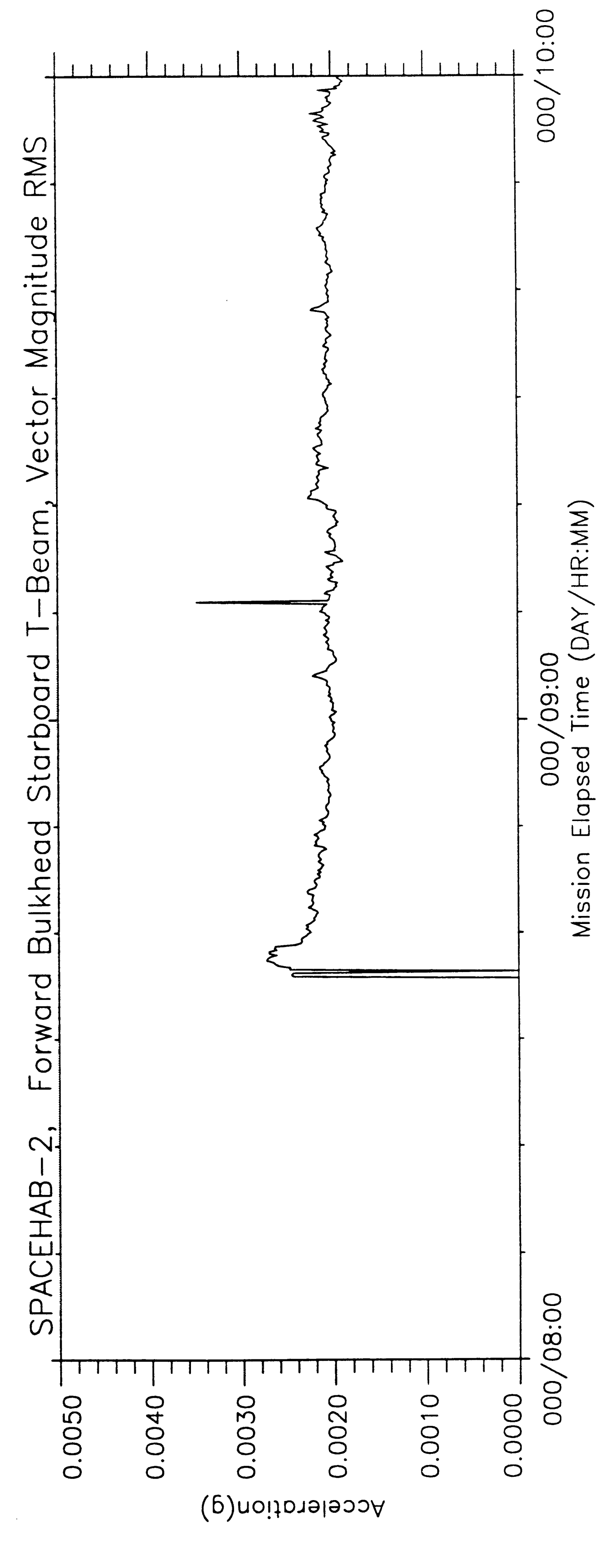
Mission Elapsed Time (DAY/HR:MM)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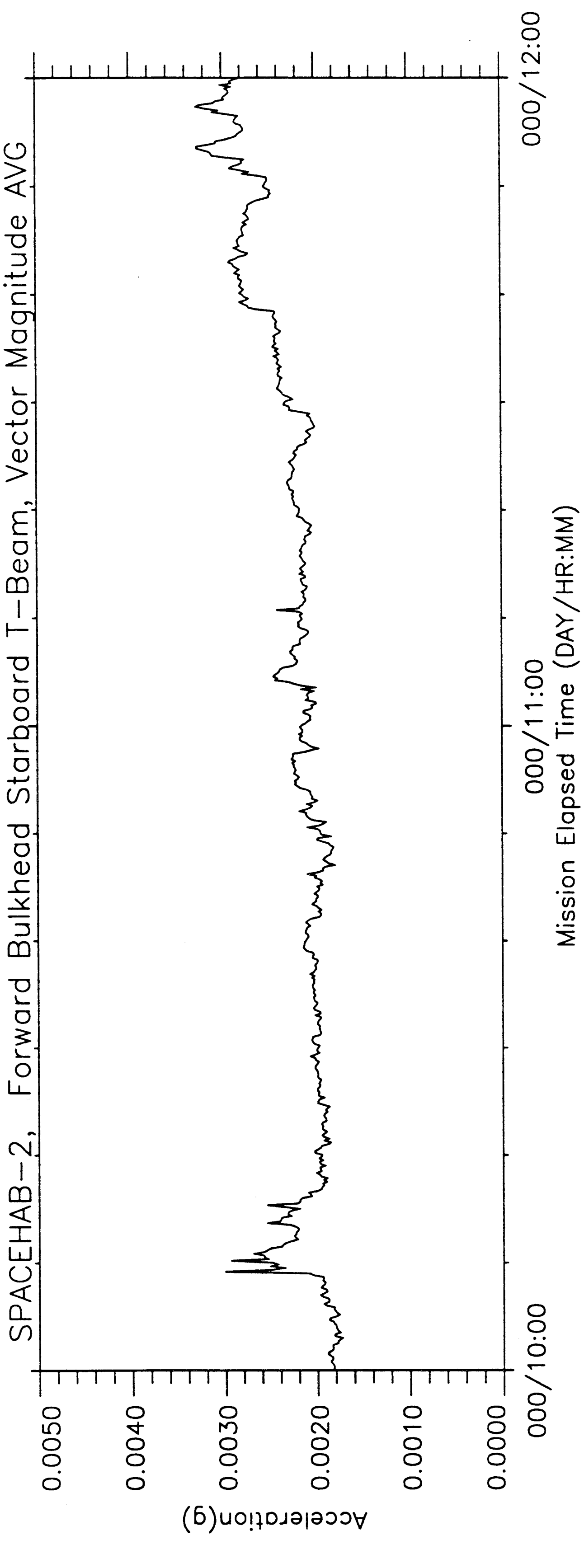
Mission Elapsed Time (DAY/HR:MM)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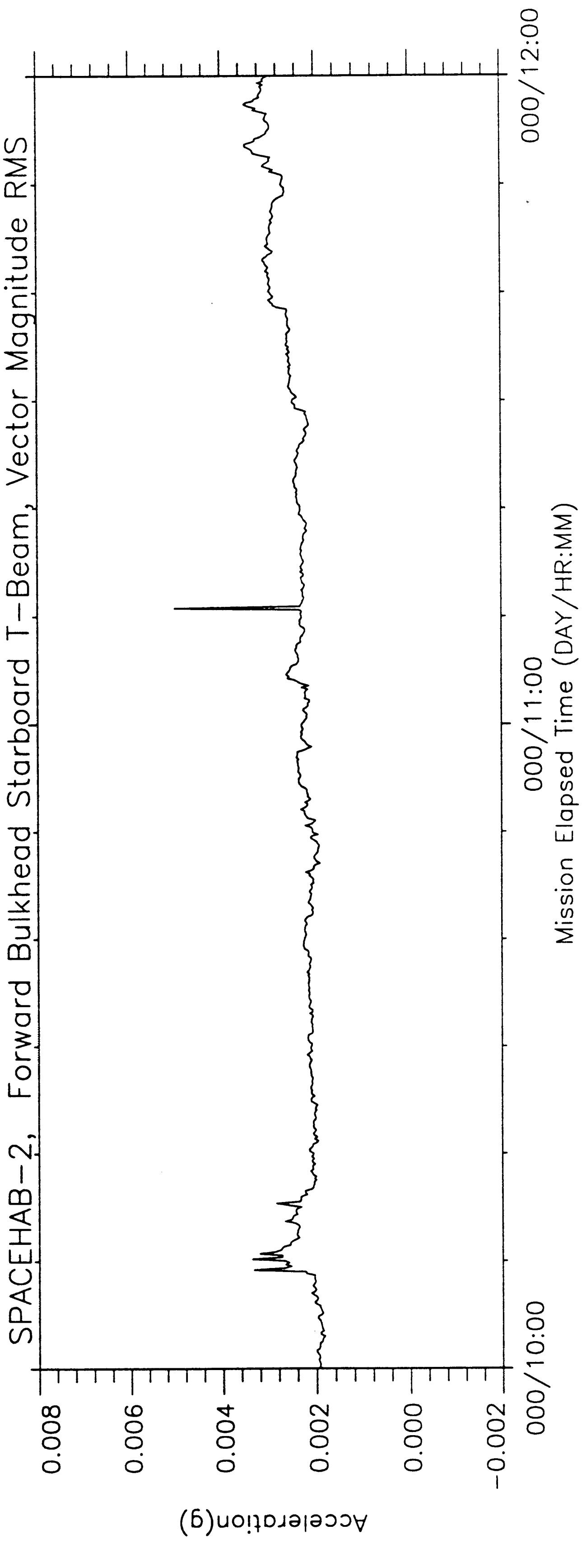
Mission Elapsed Time (DAY/HR:MM)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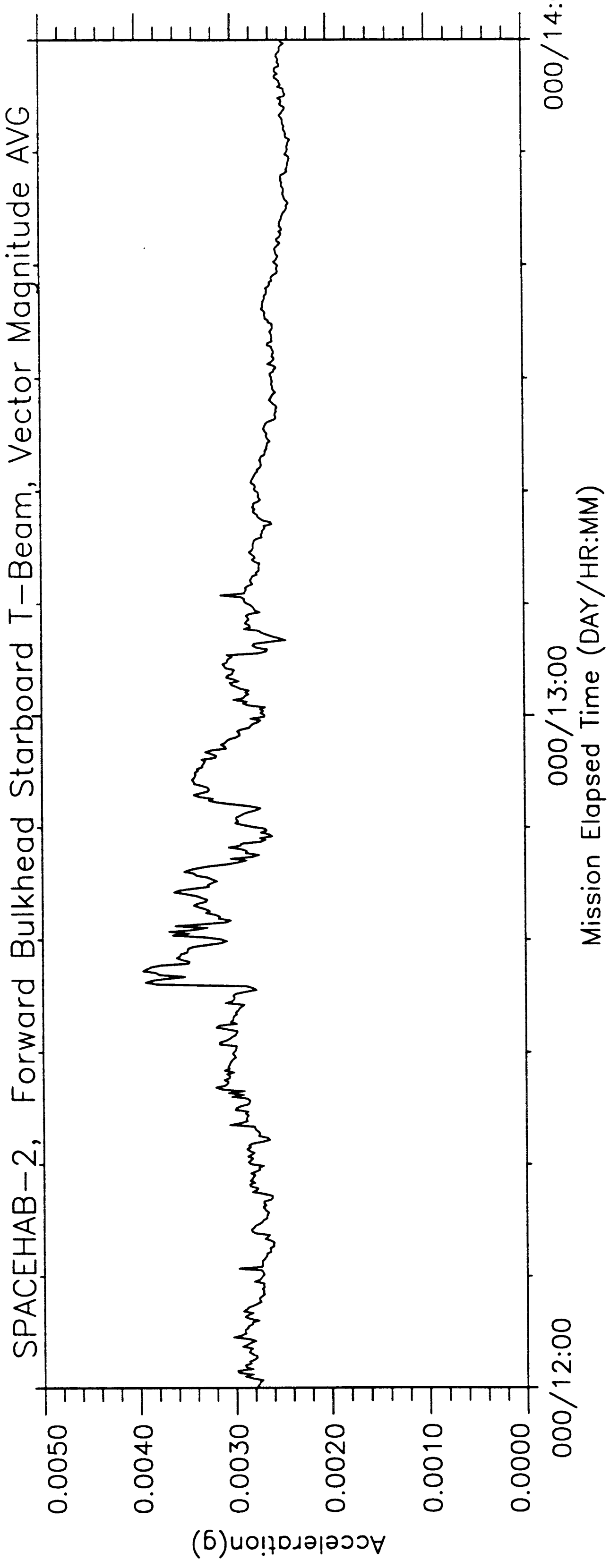
Mission Elapsed Time (DAY/HR:MM)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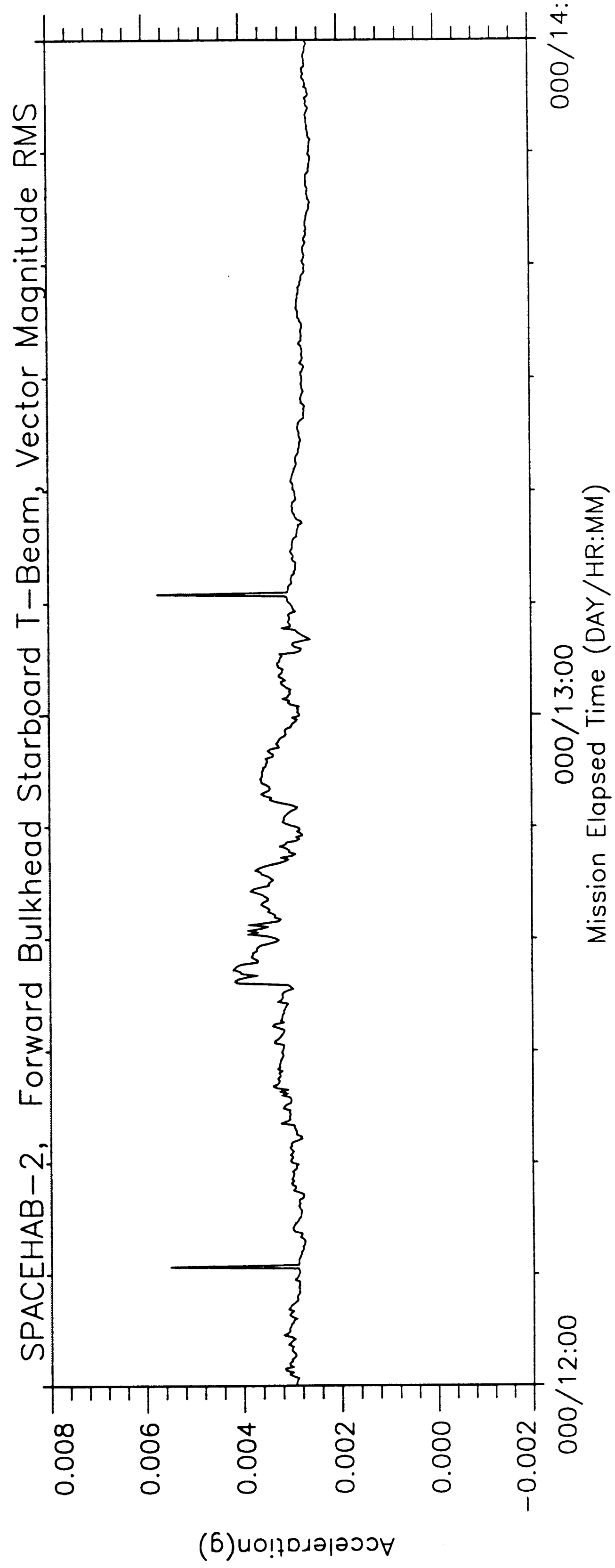
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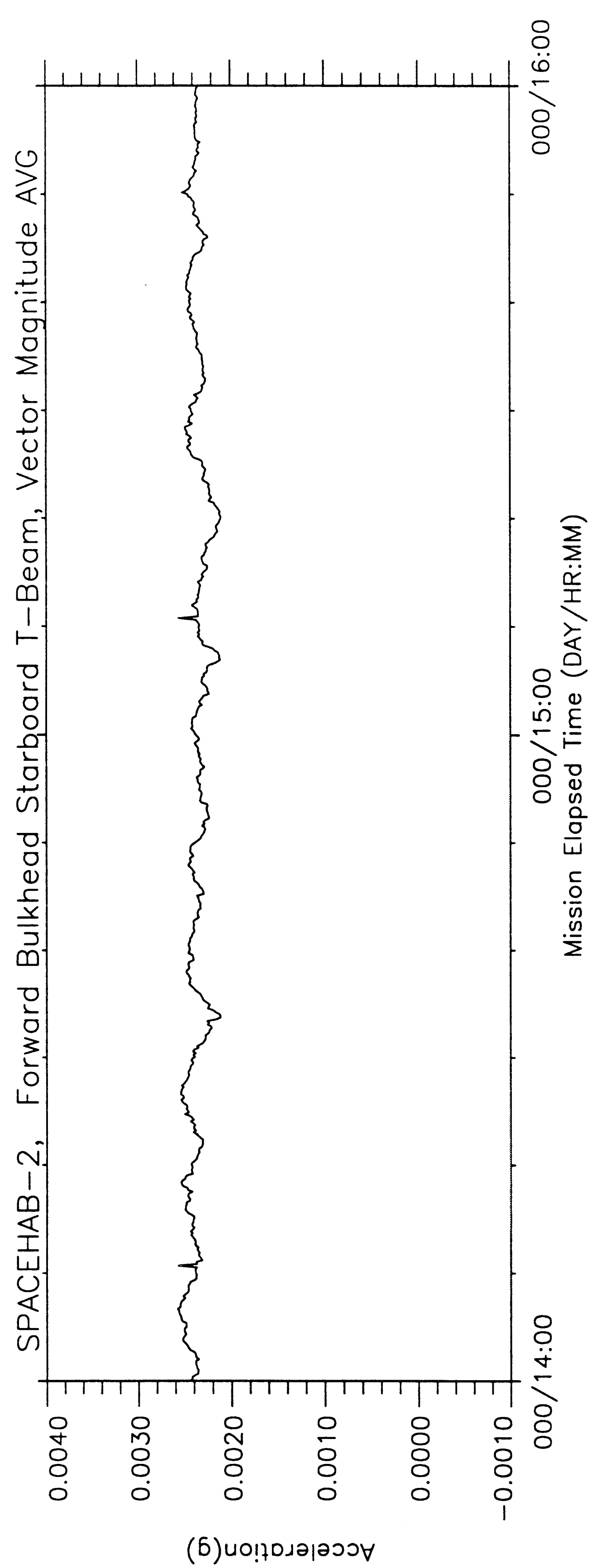
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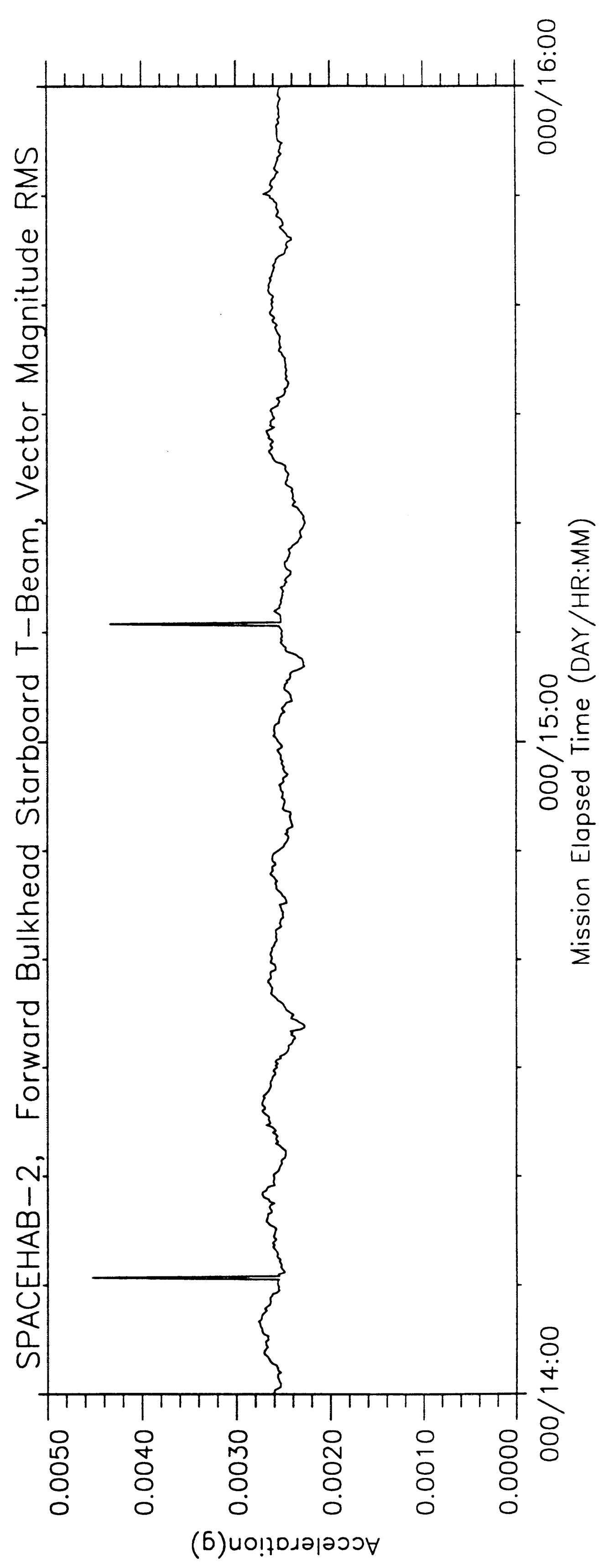
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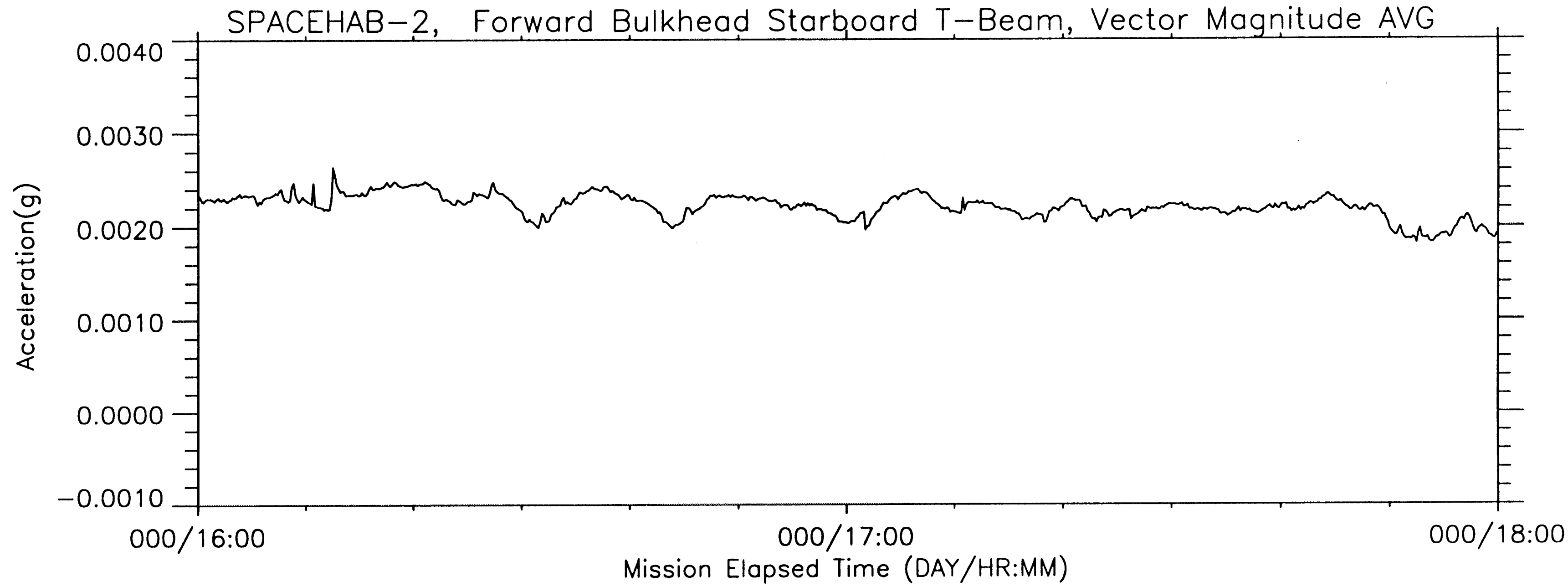
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Acceleration(g)
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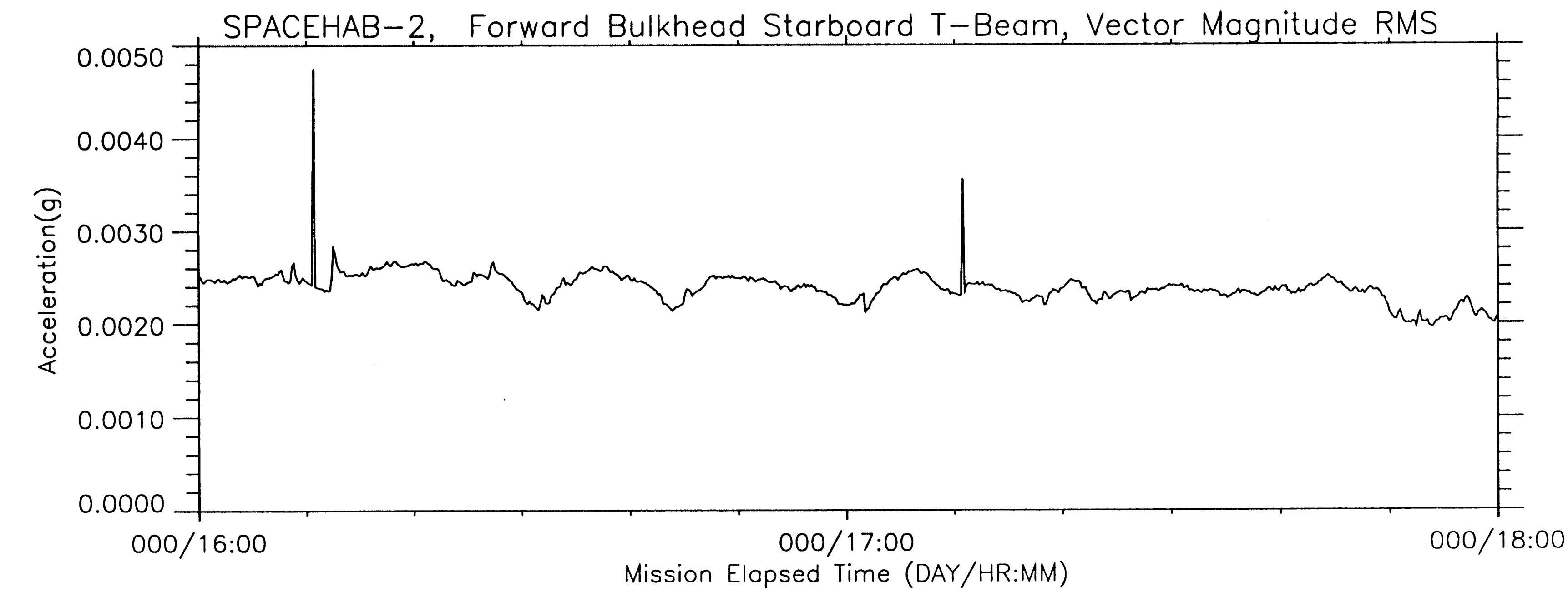
Mission Elapsed Time (DAY/HR:MM)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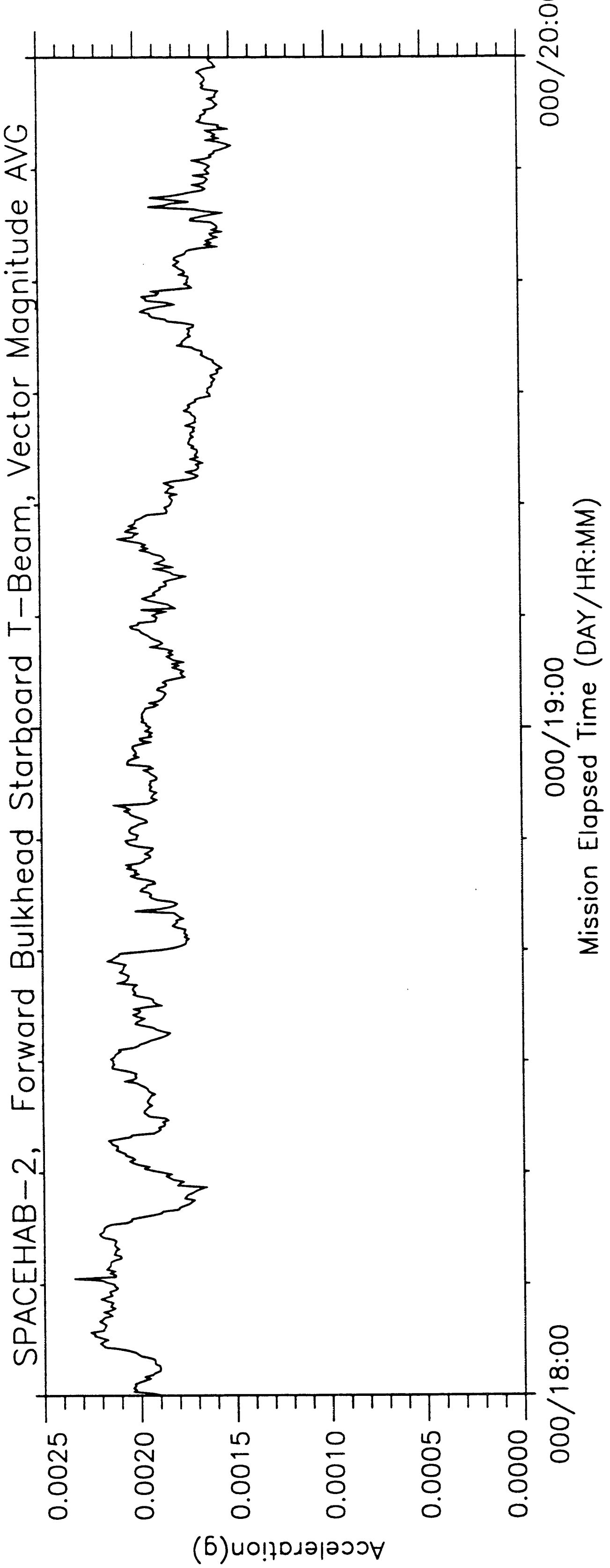
Mission Elapsed Time (DAY/HR:MM)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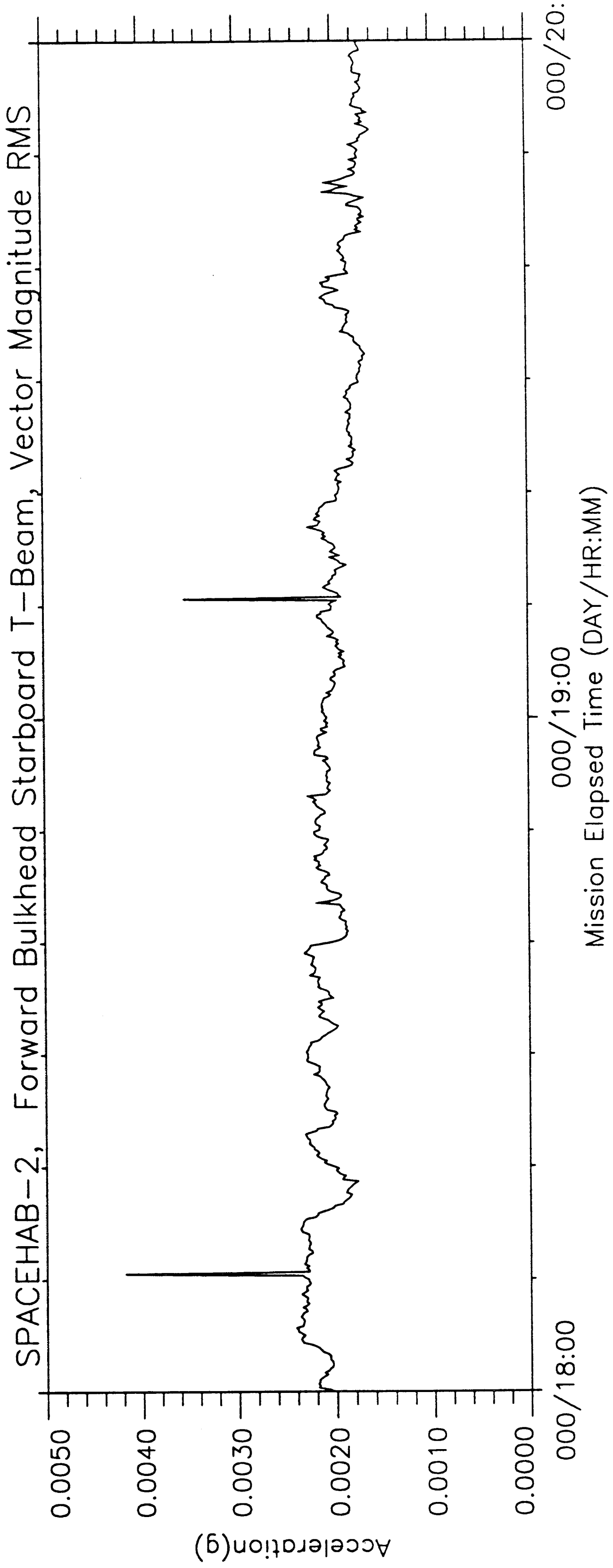
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Mission Elapsed Time (DAY/HR:MM)

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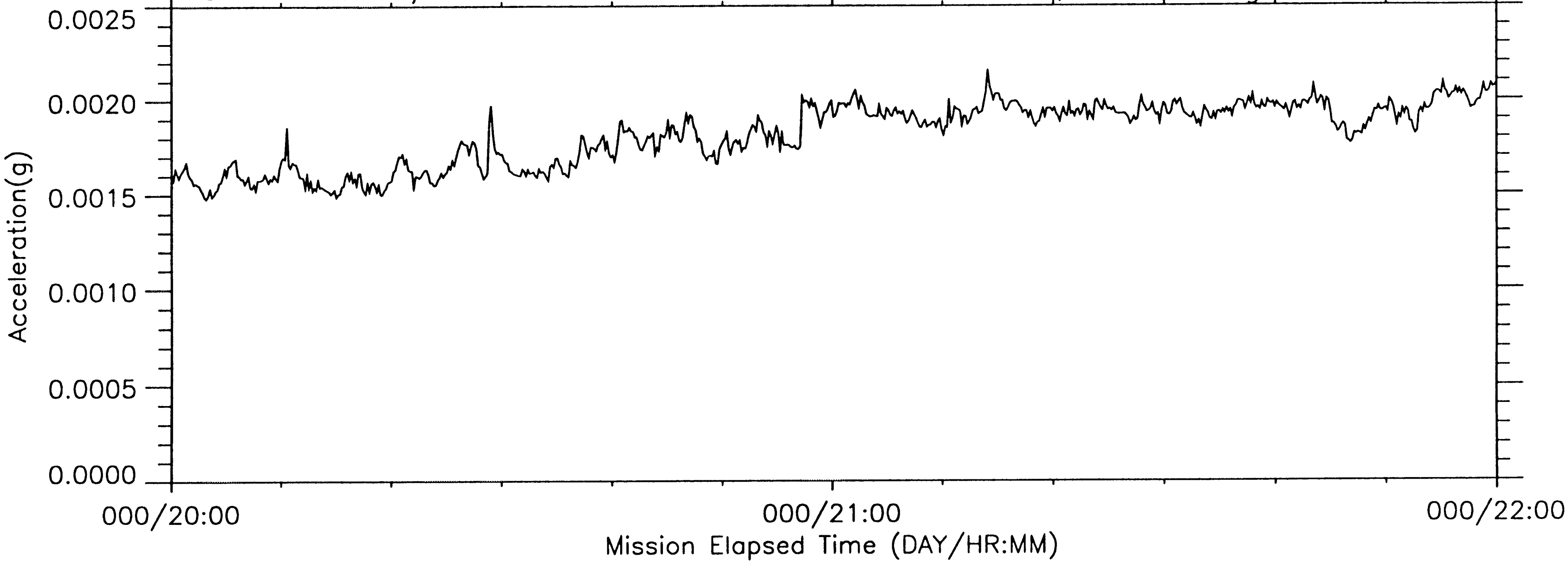

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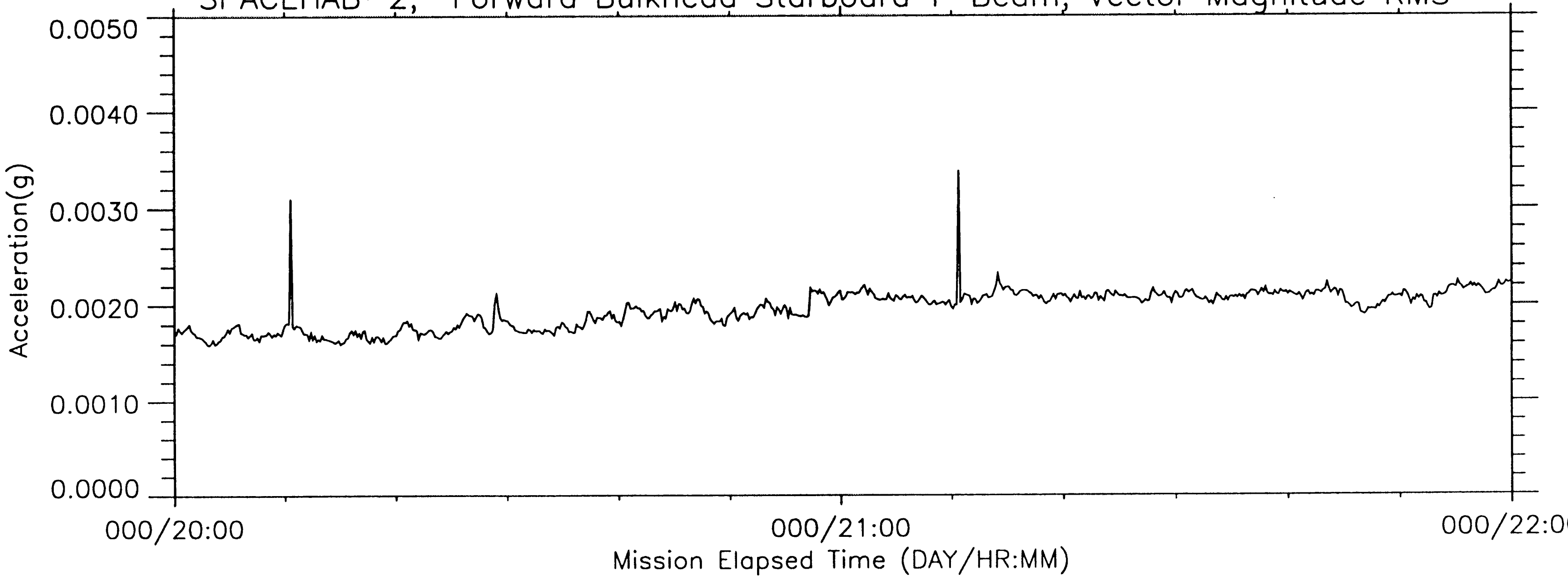

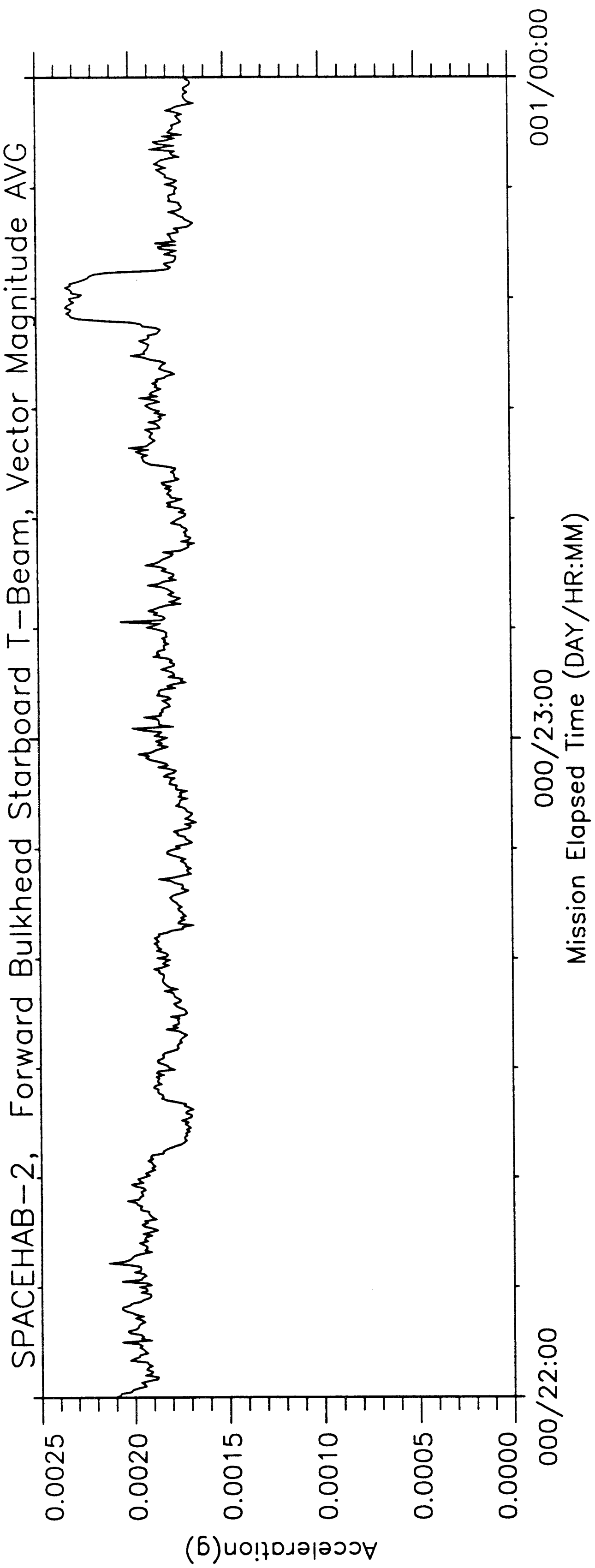
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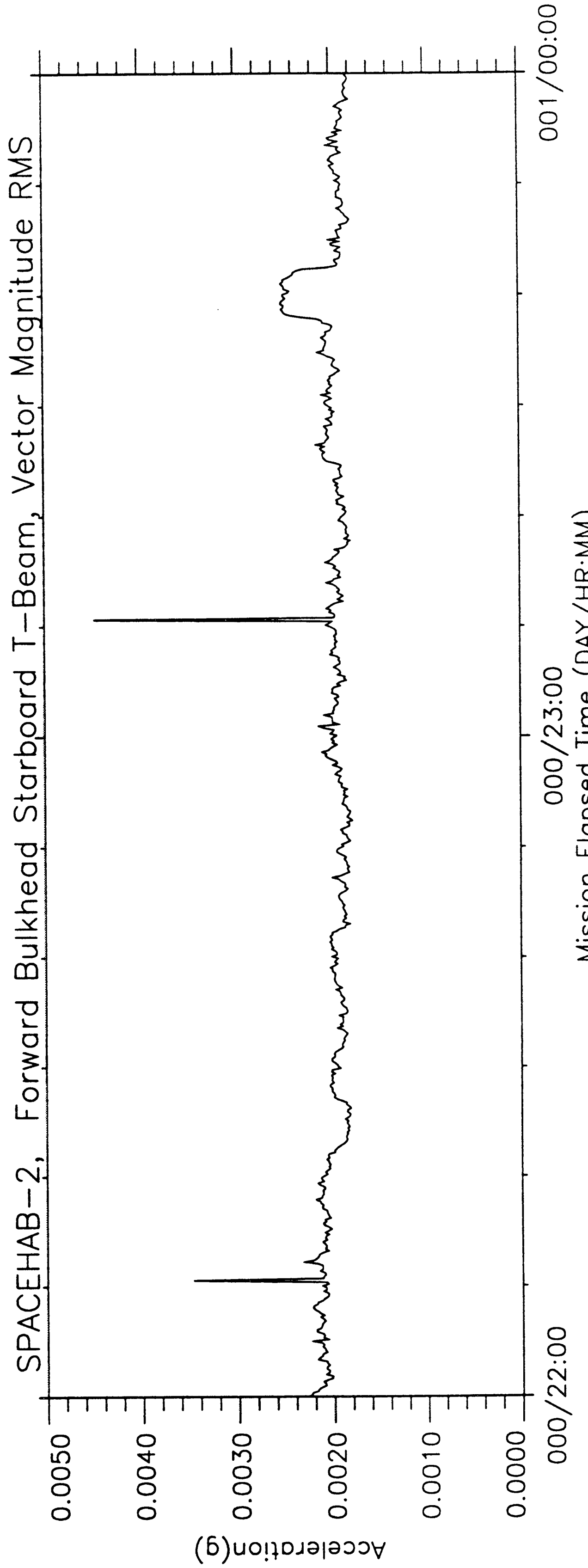
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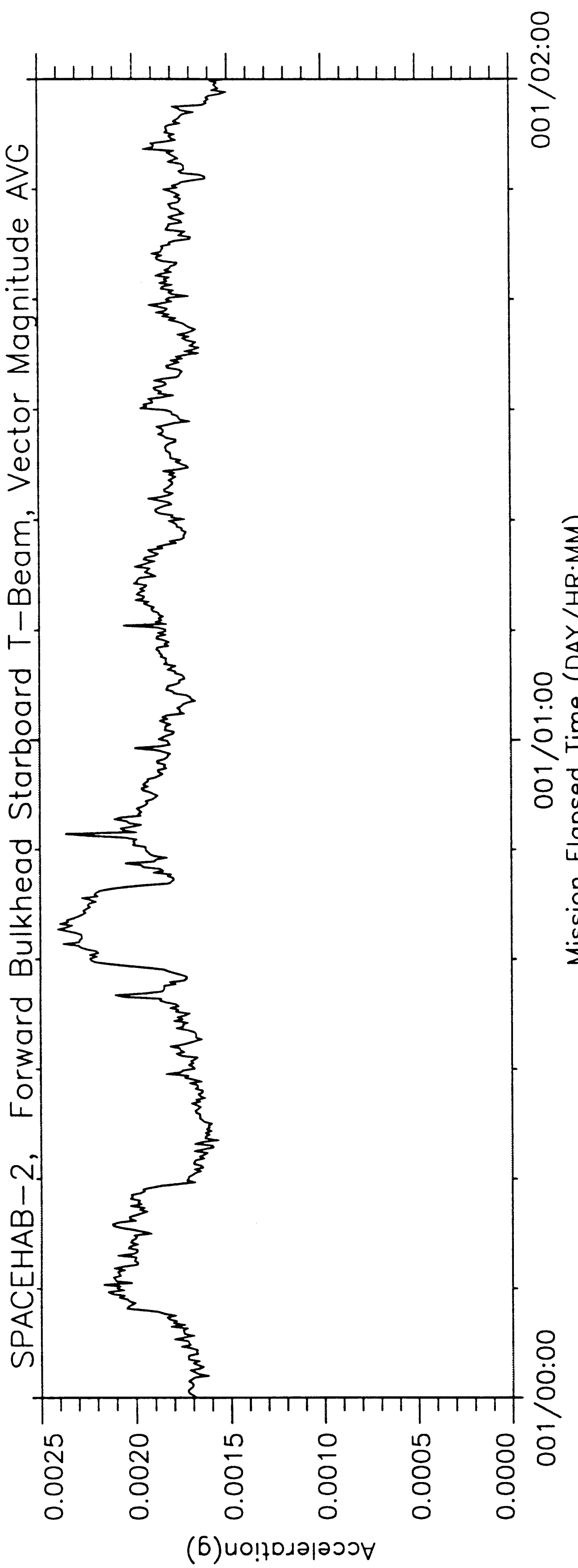
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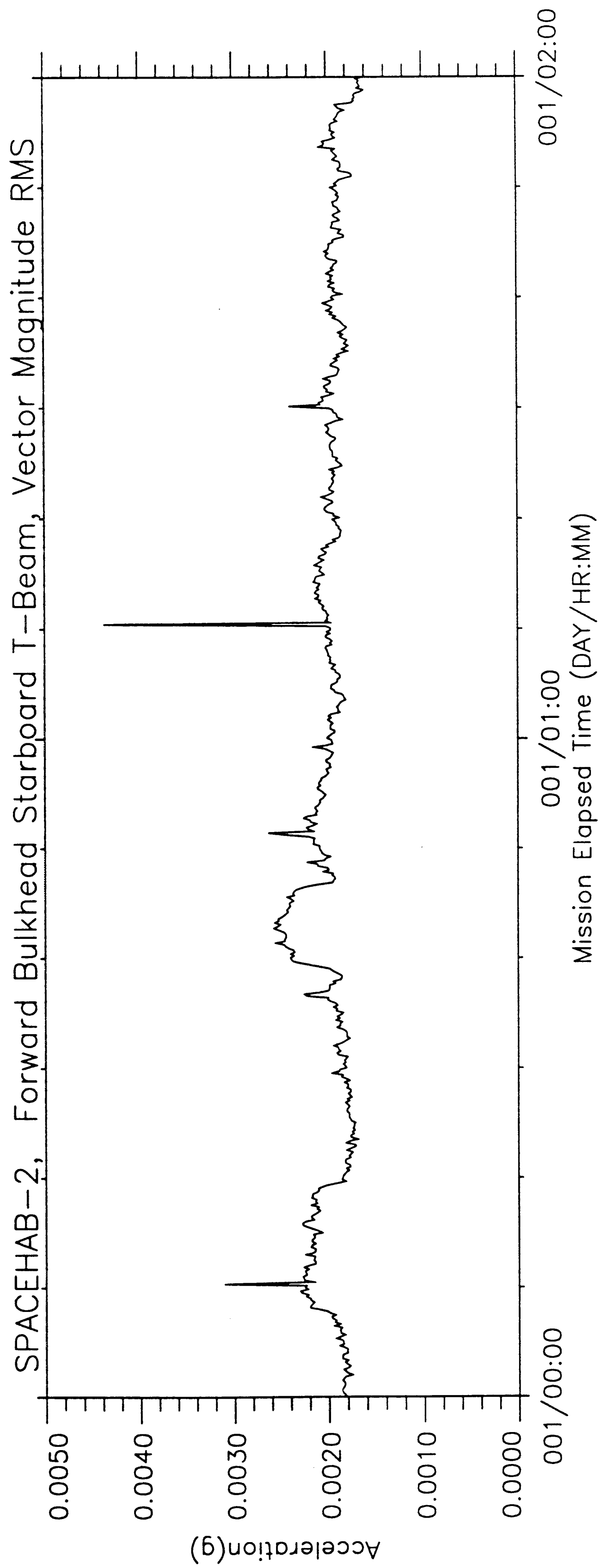
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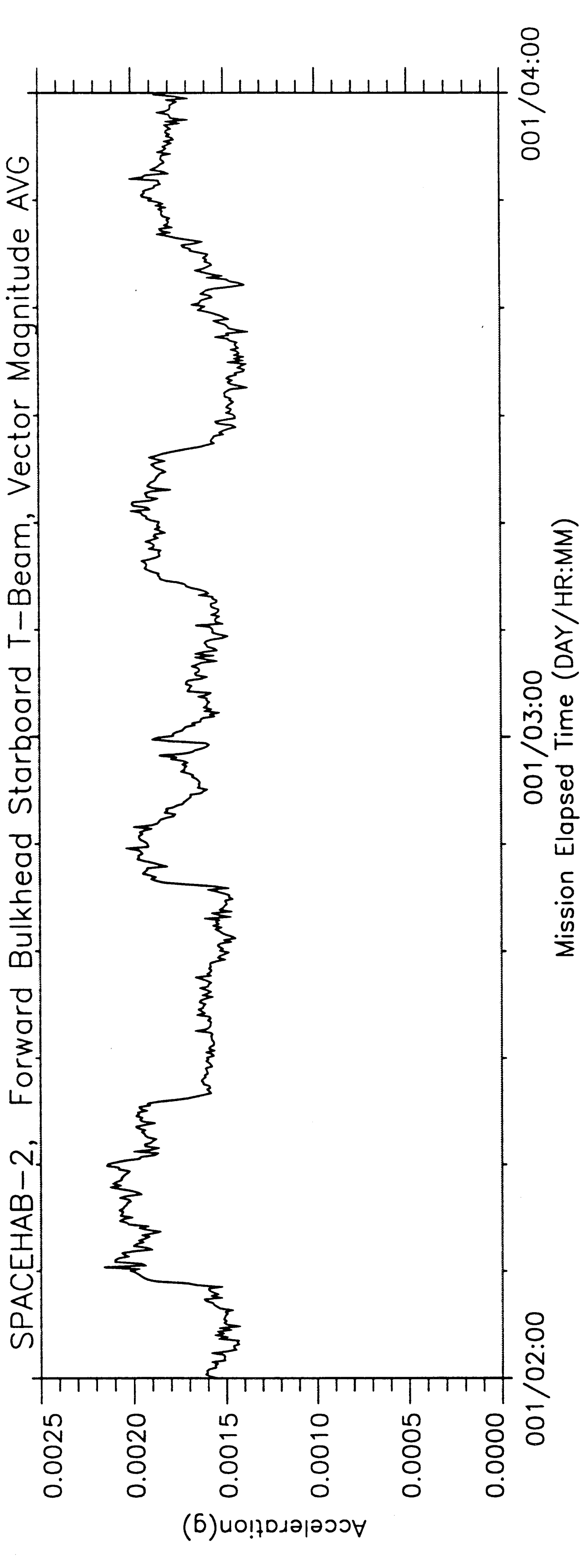
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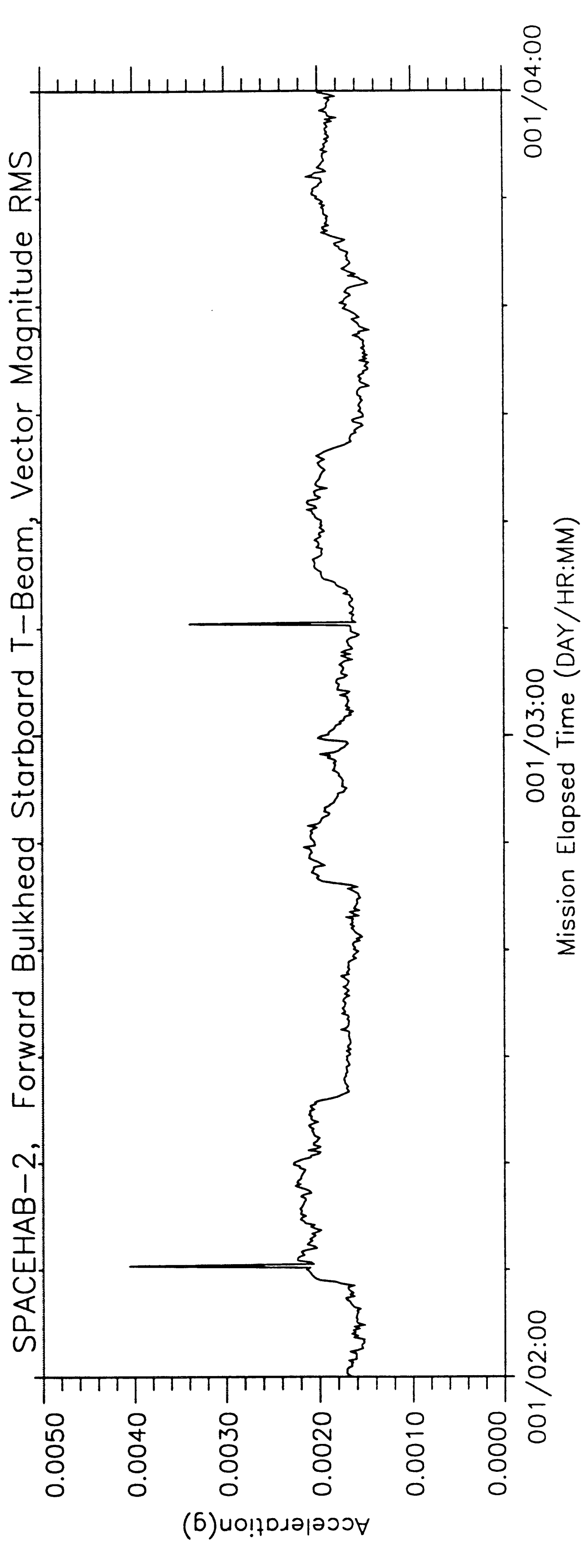
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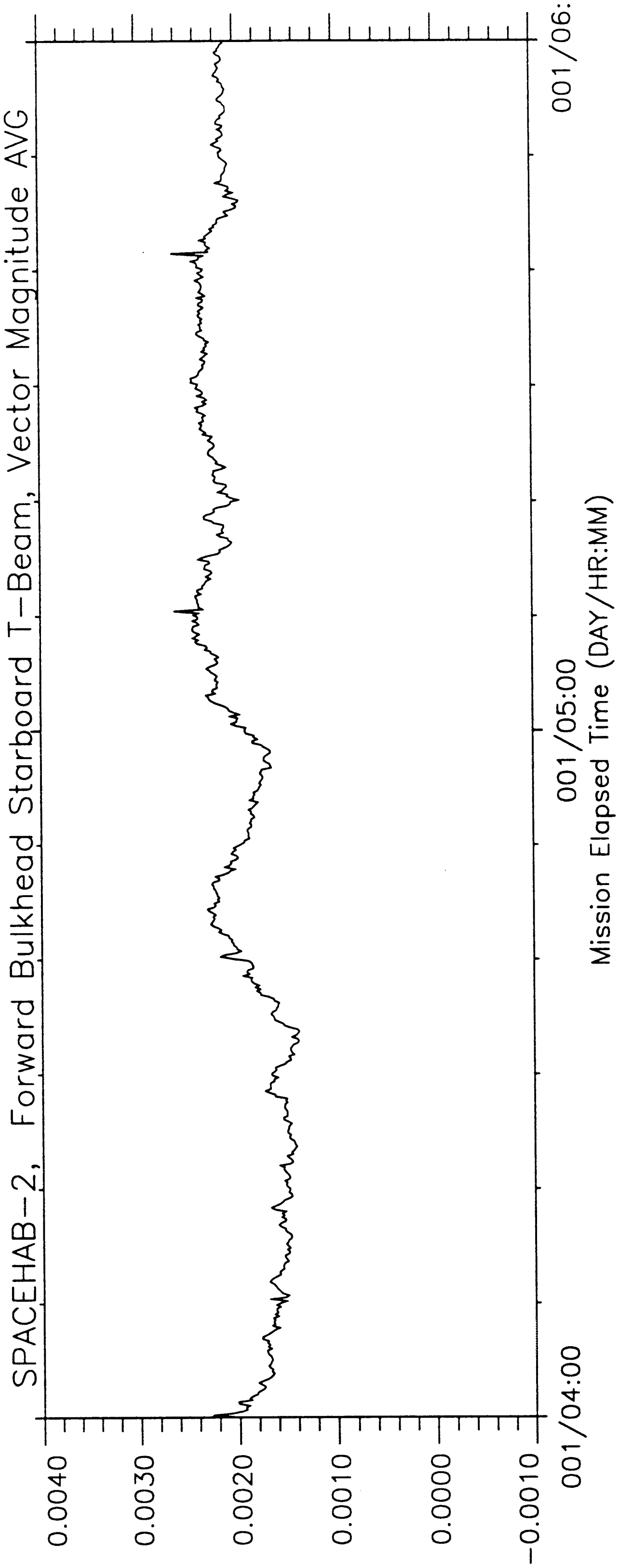
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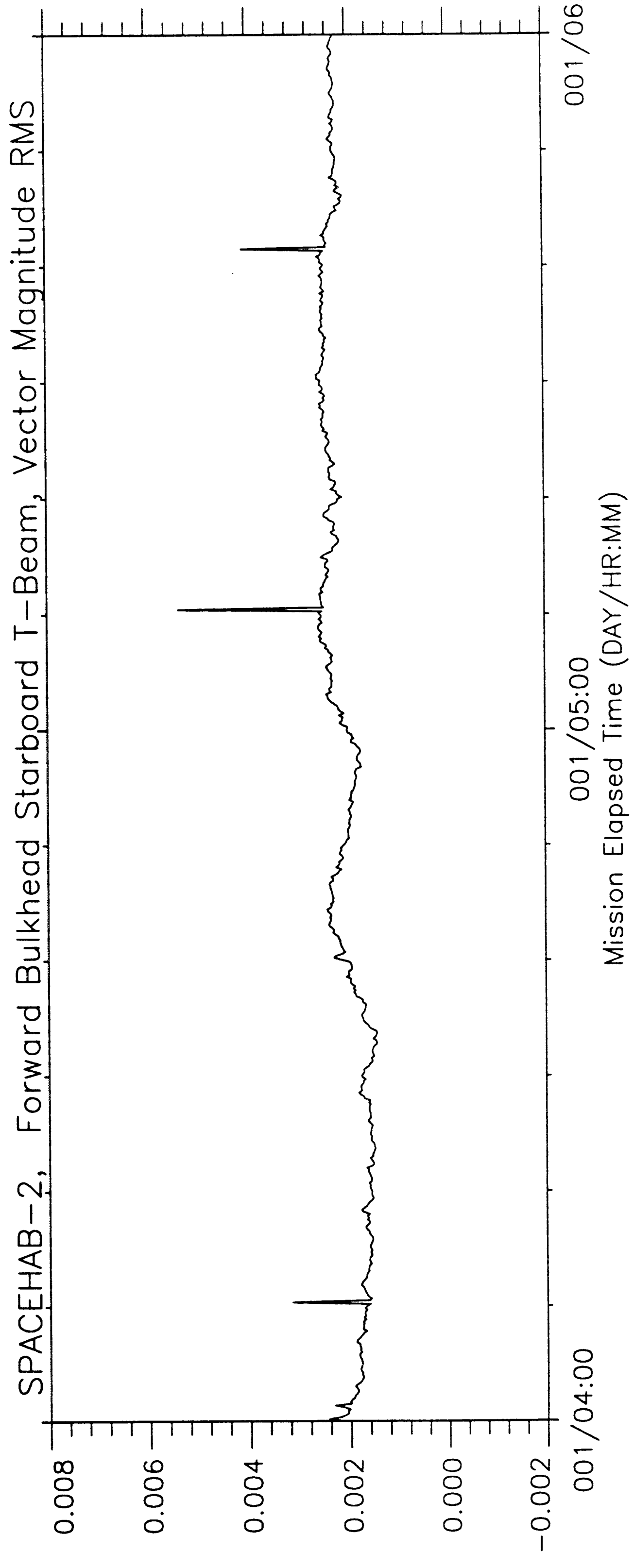
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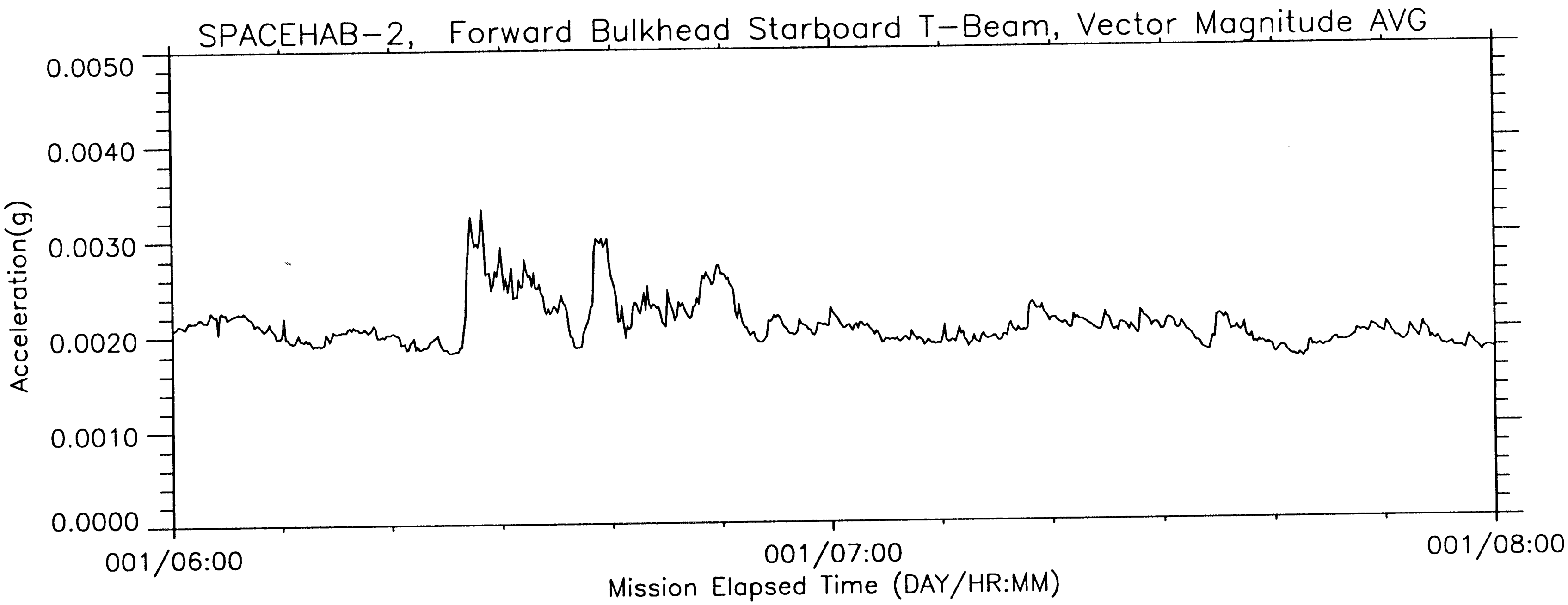
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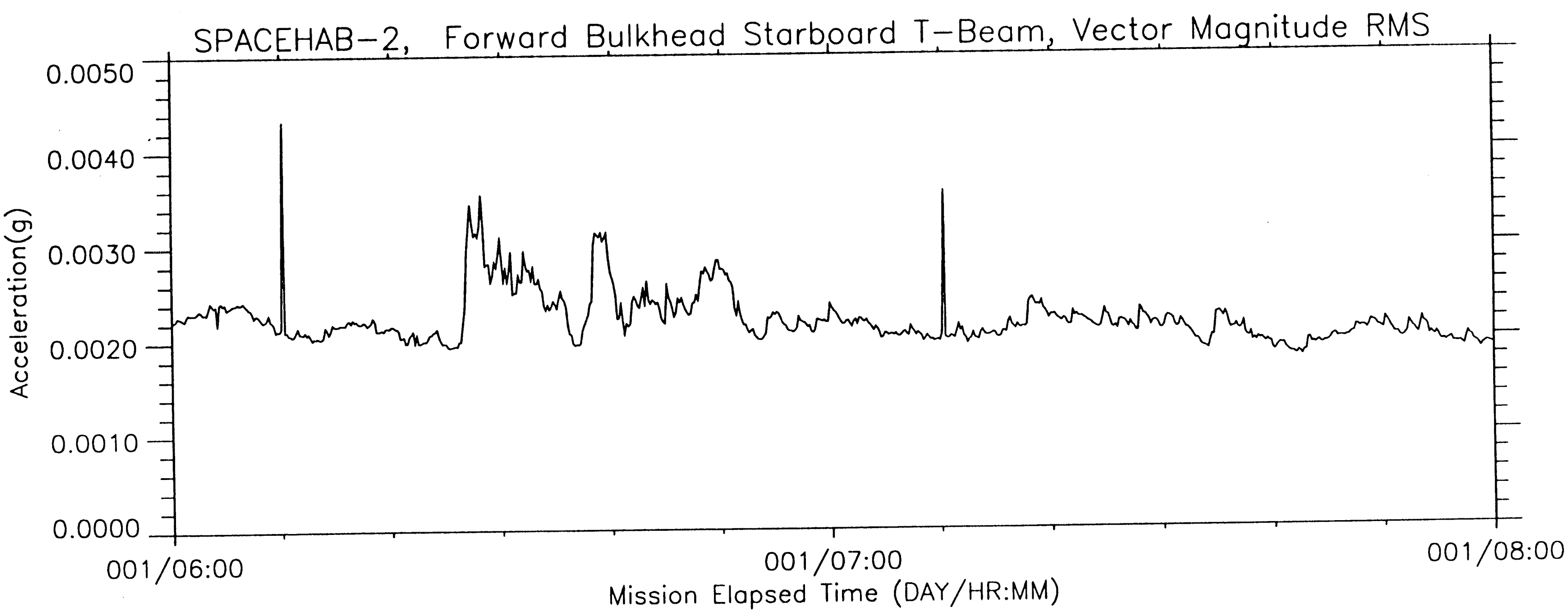
Mission Elapsed Time (DAY/HR:MM)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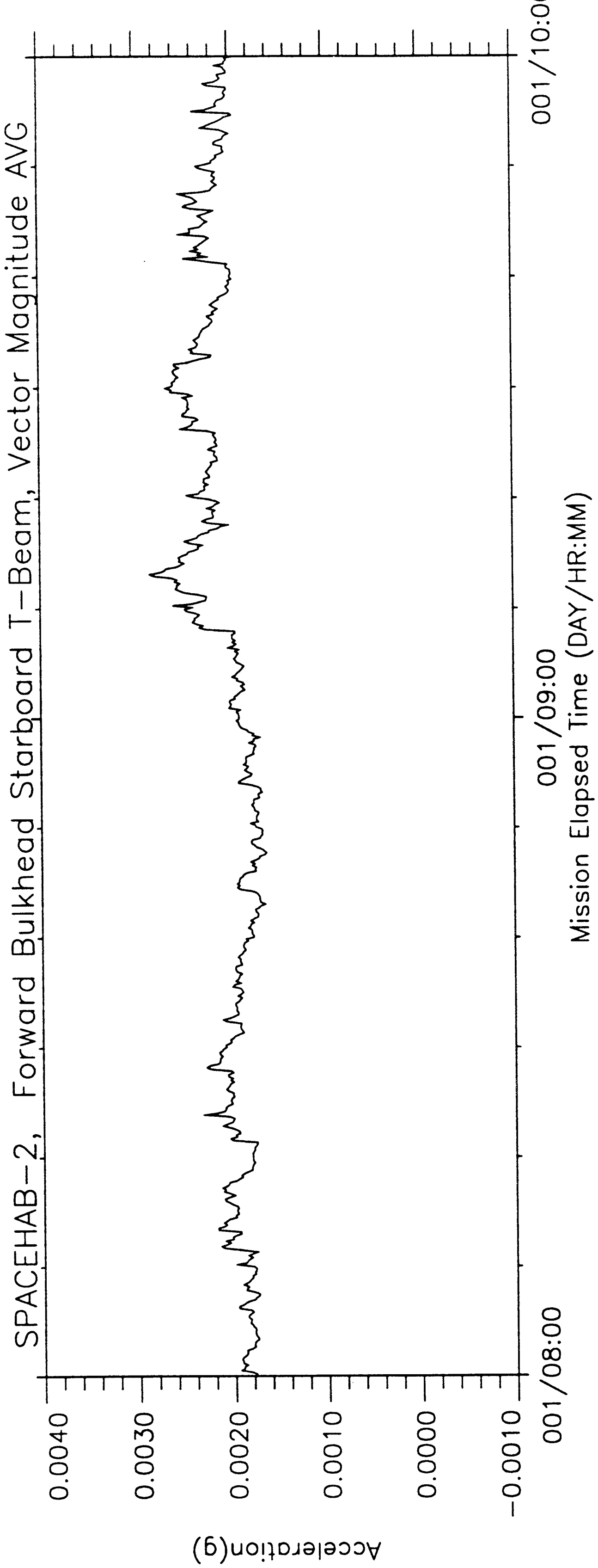
Mission Elapsed Time (DAY/HR:MM)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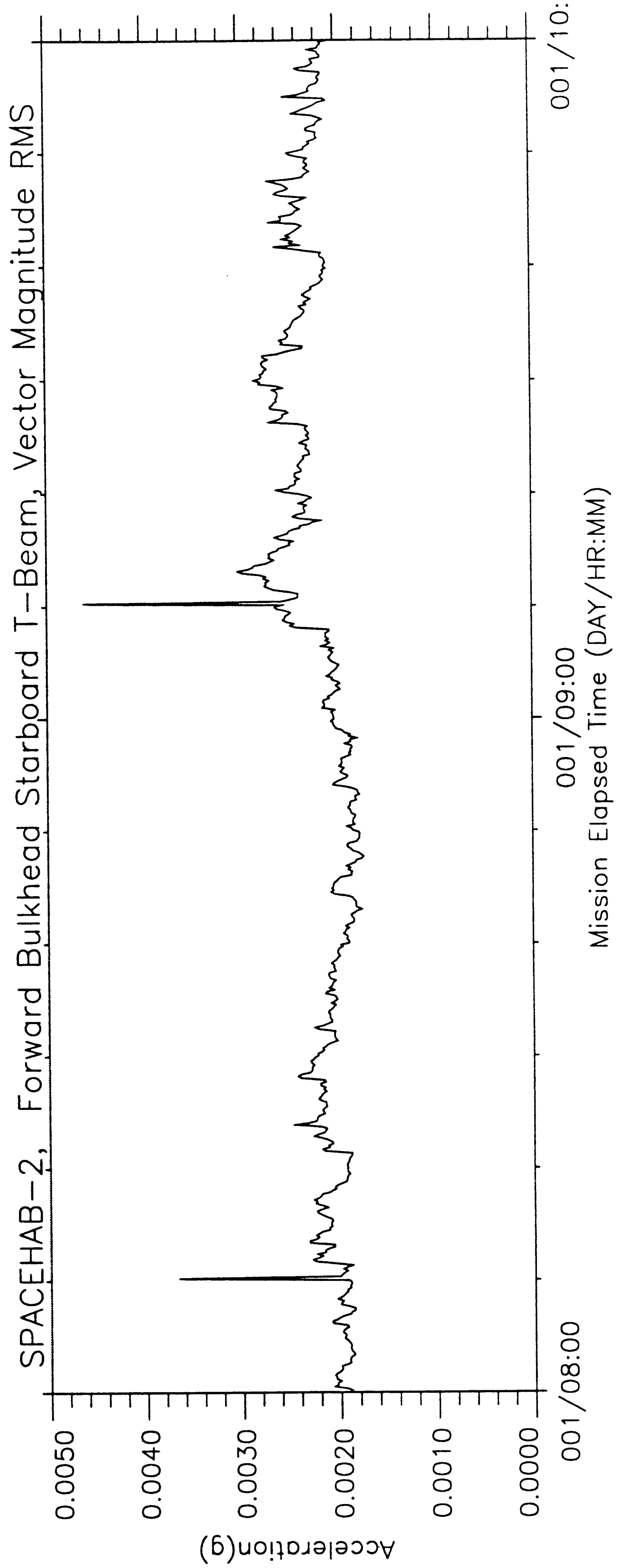
Mission Elapsed Time (DAY/HR:MM)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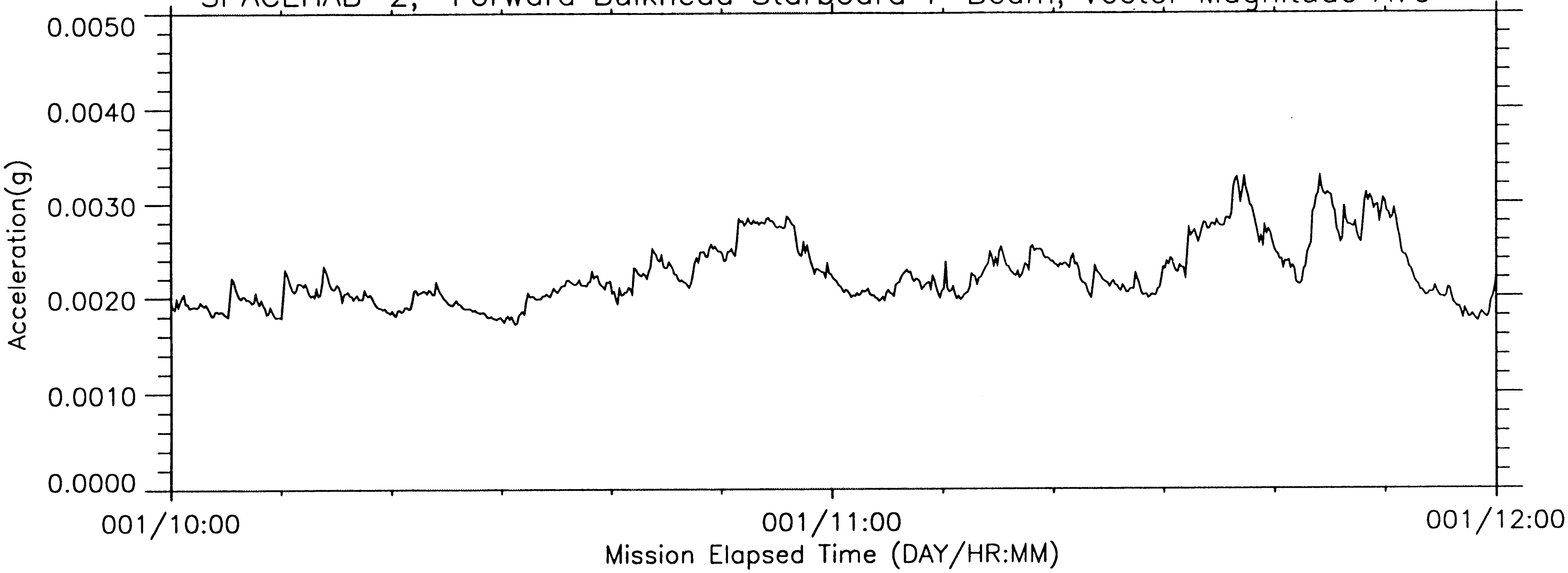
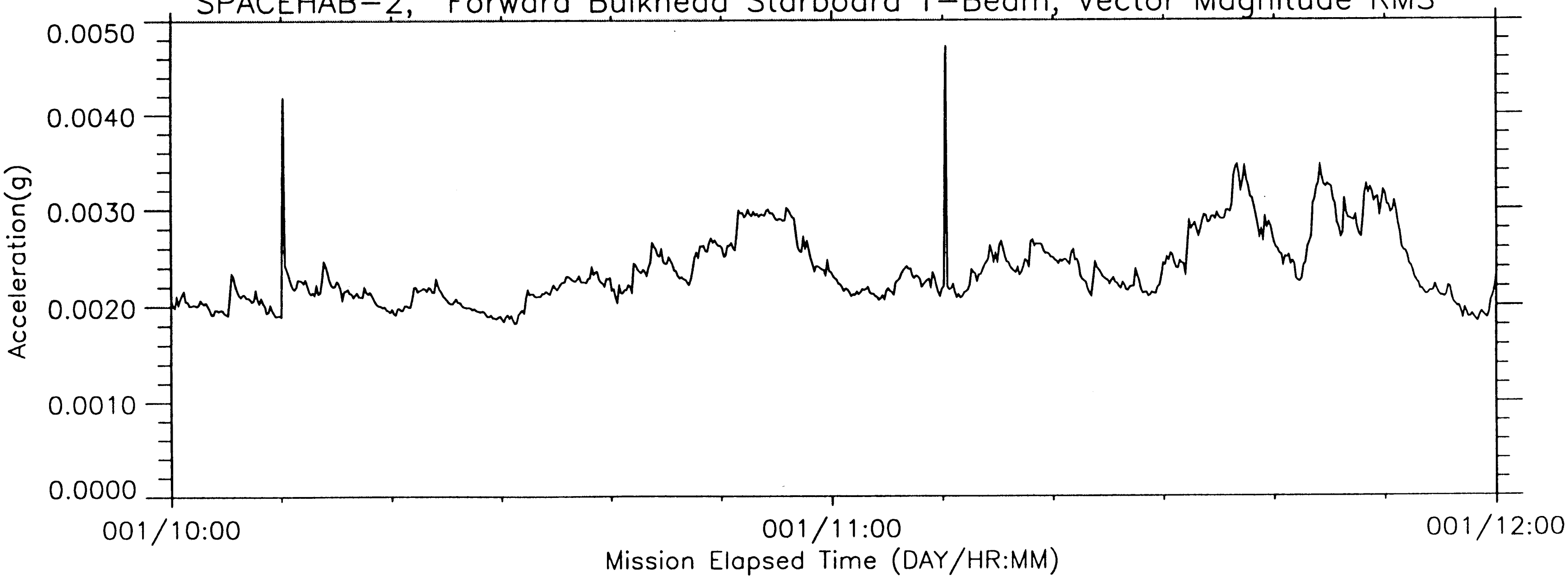
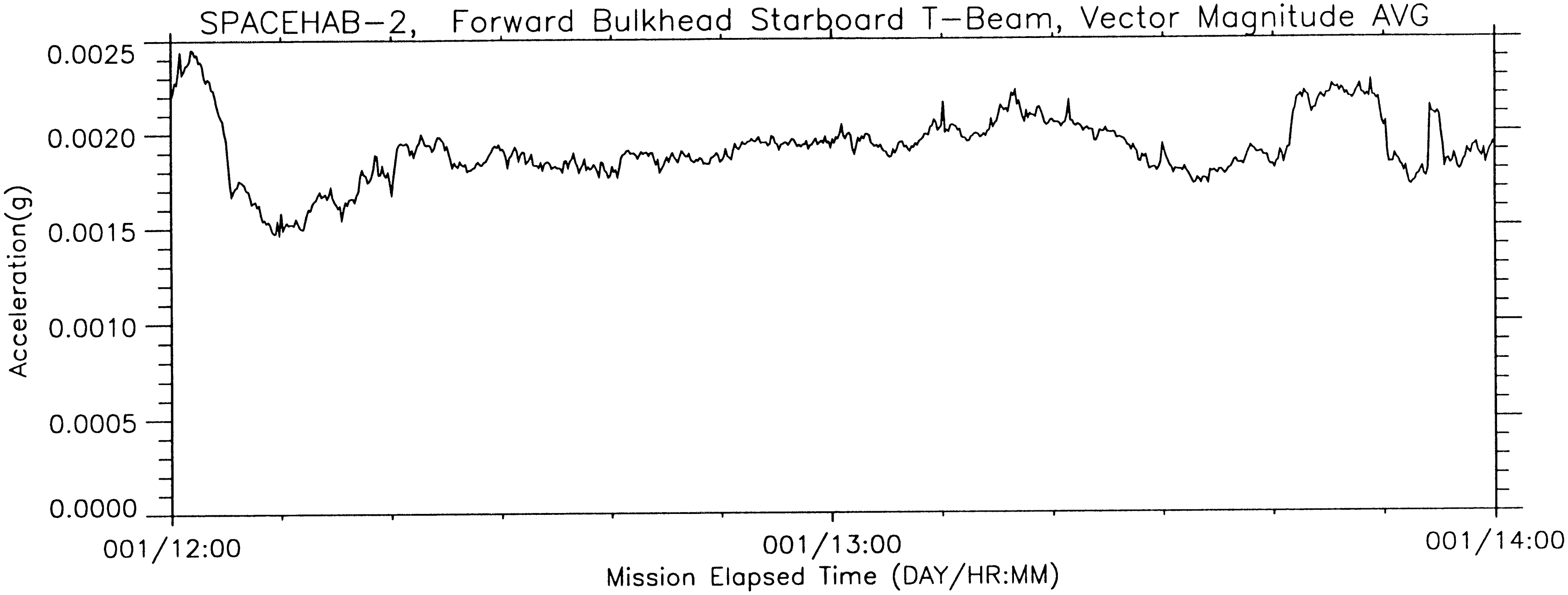
Mission Elapsed Time (DAY/HR:MM)

SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude AVG



SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude RMS




SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude AVG
Acceleration(g)
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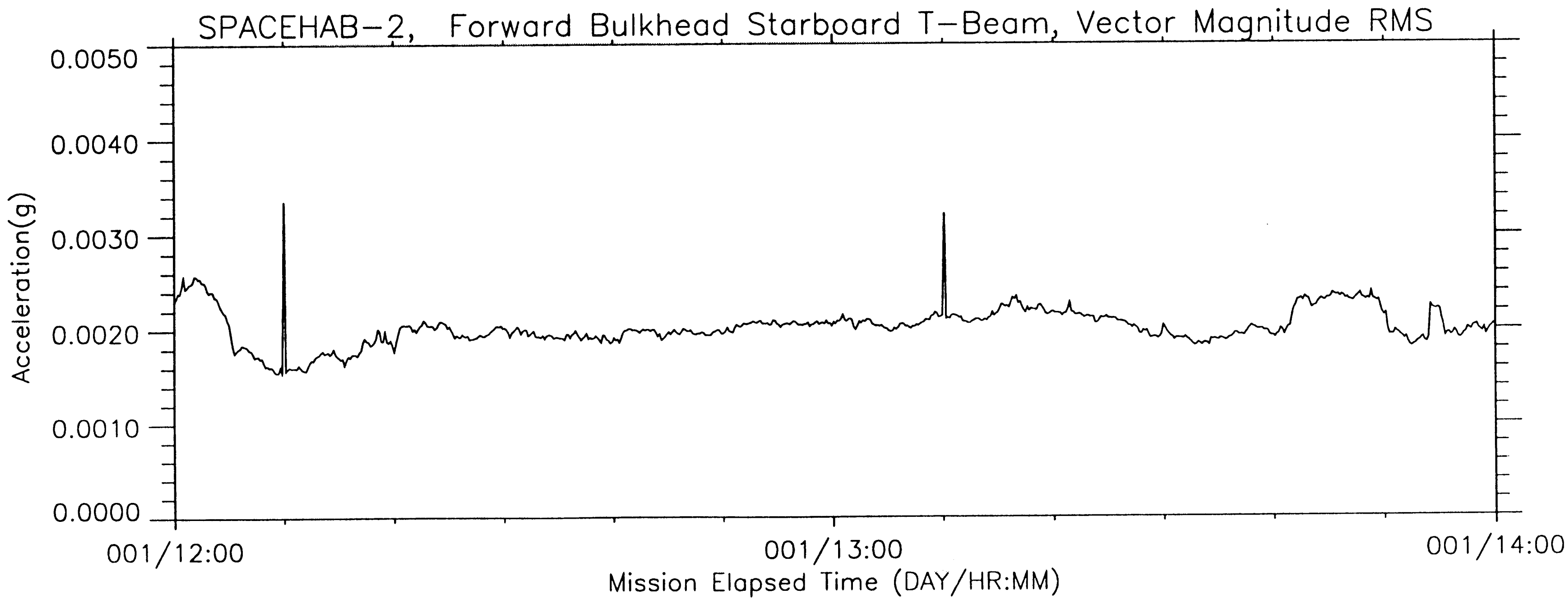
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude RMS
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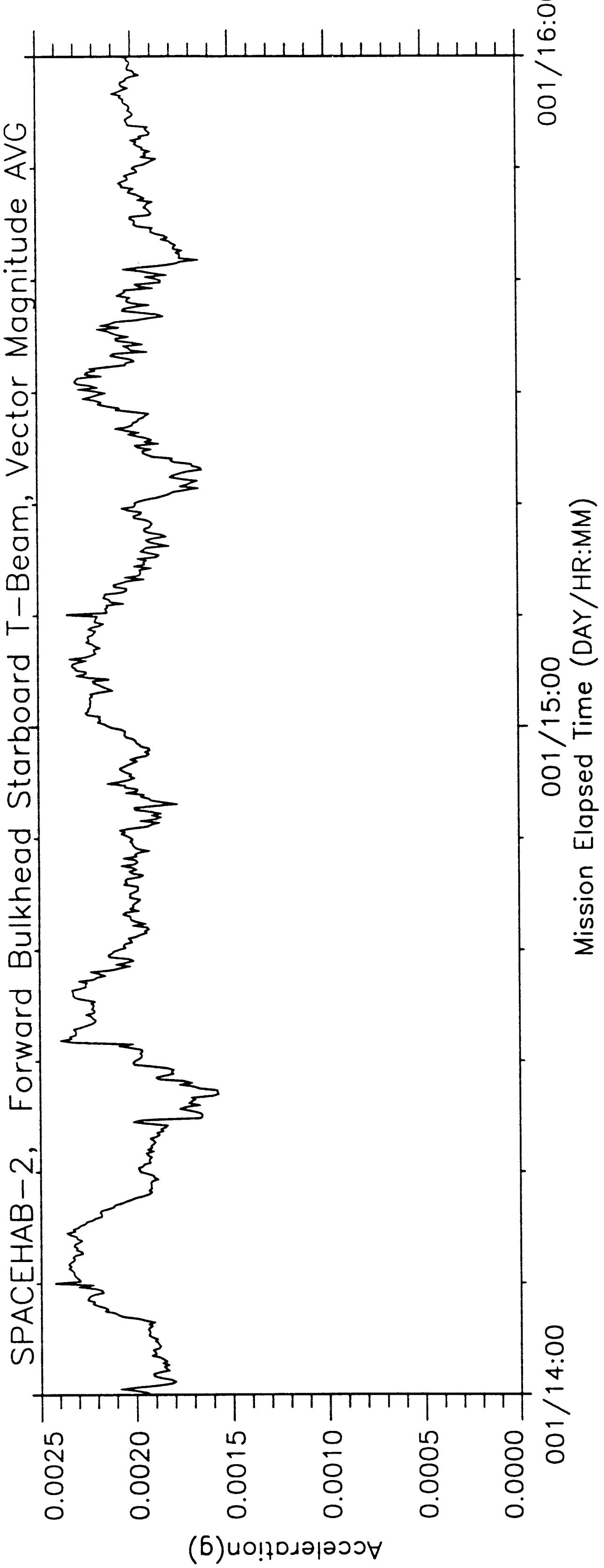
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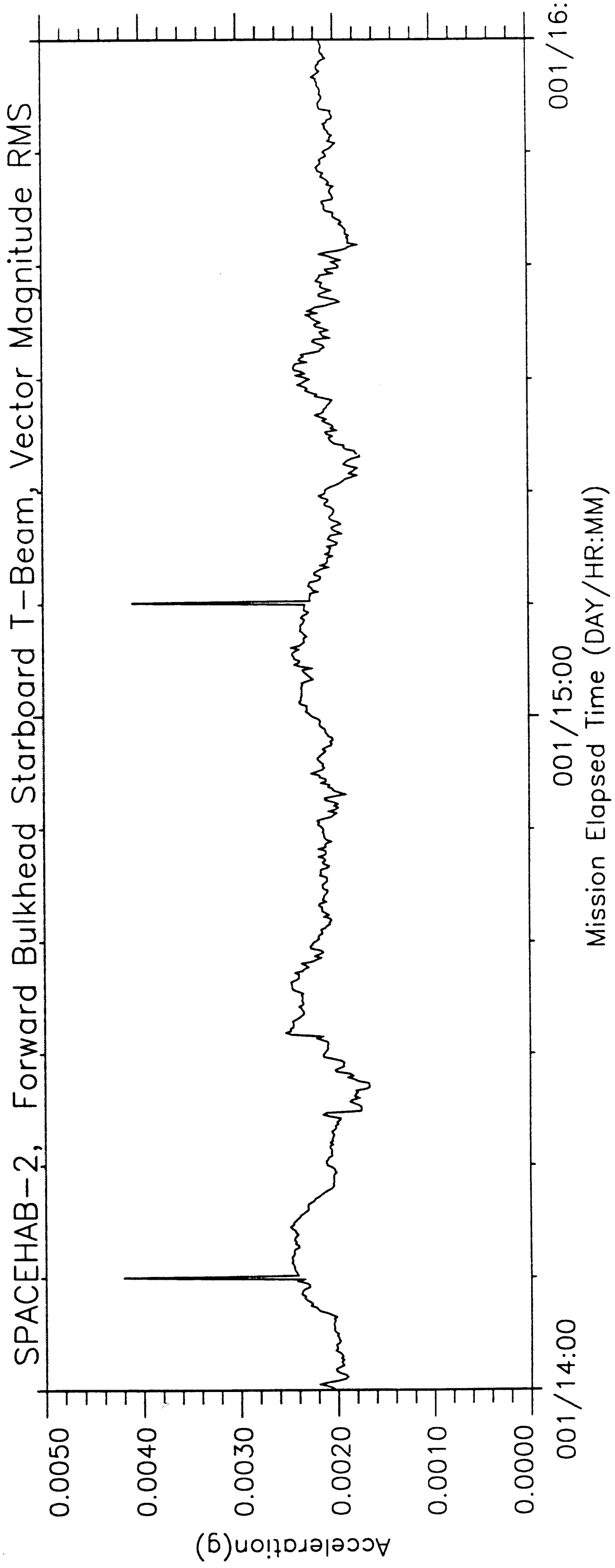
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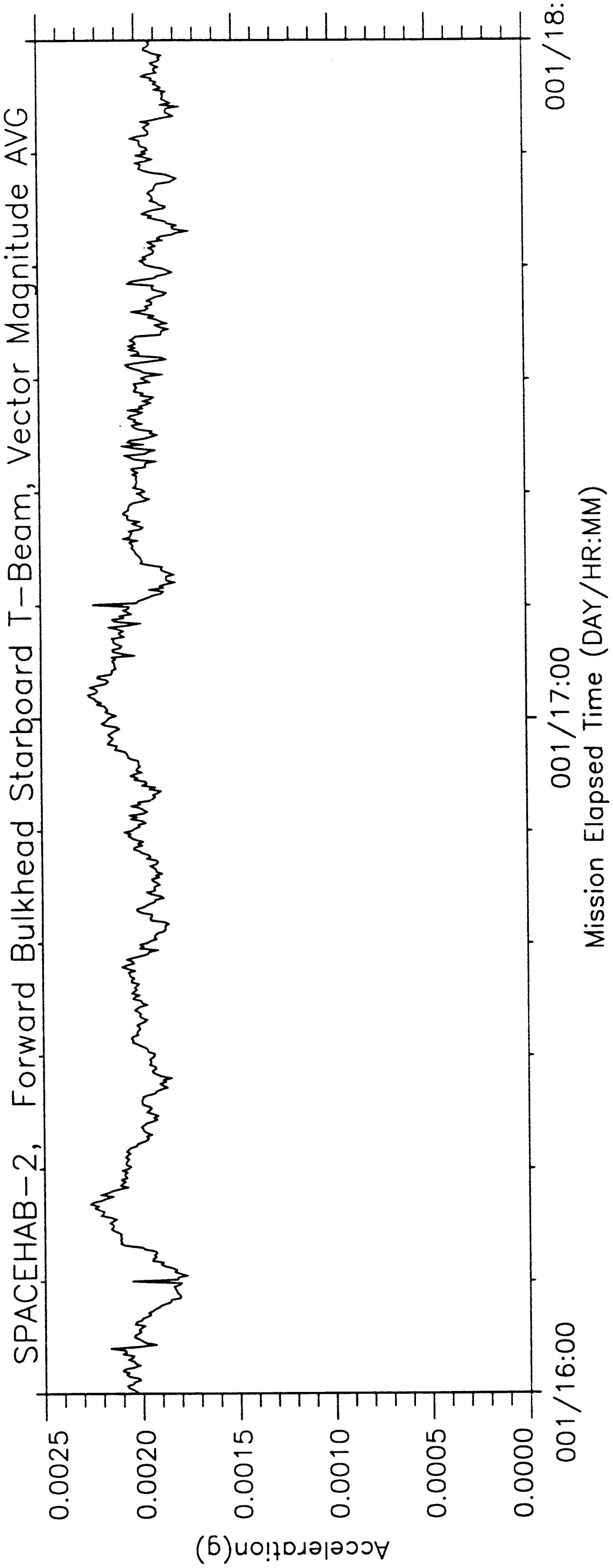
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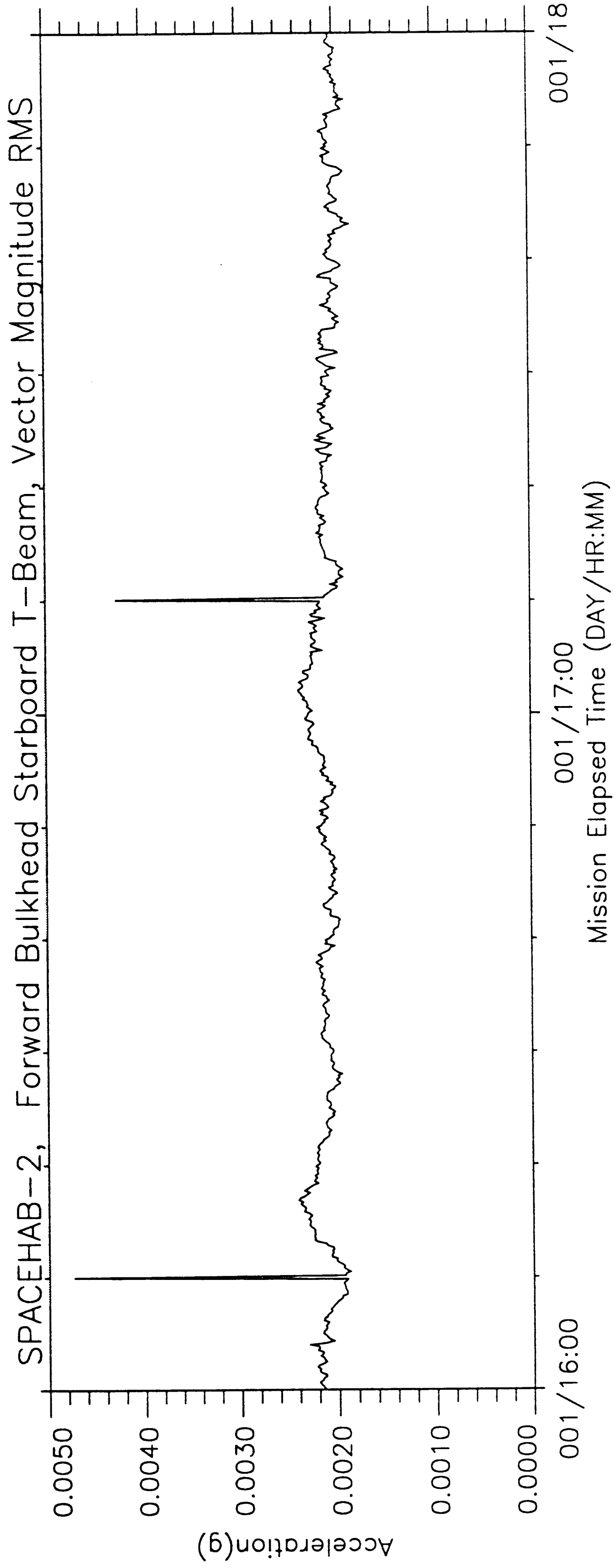
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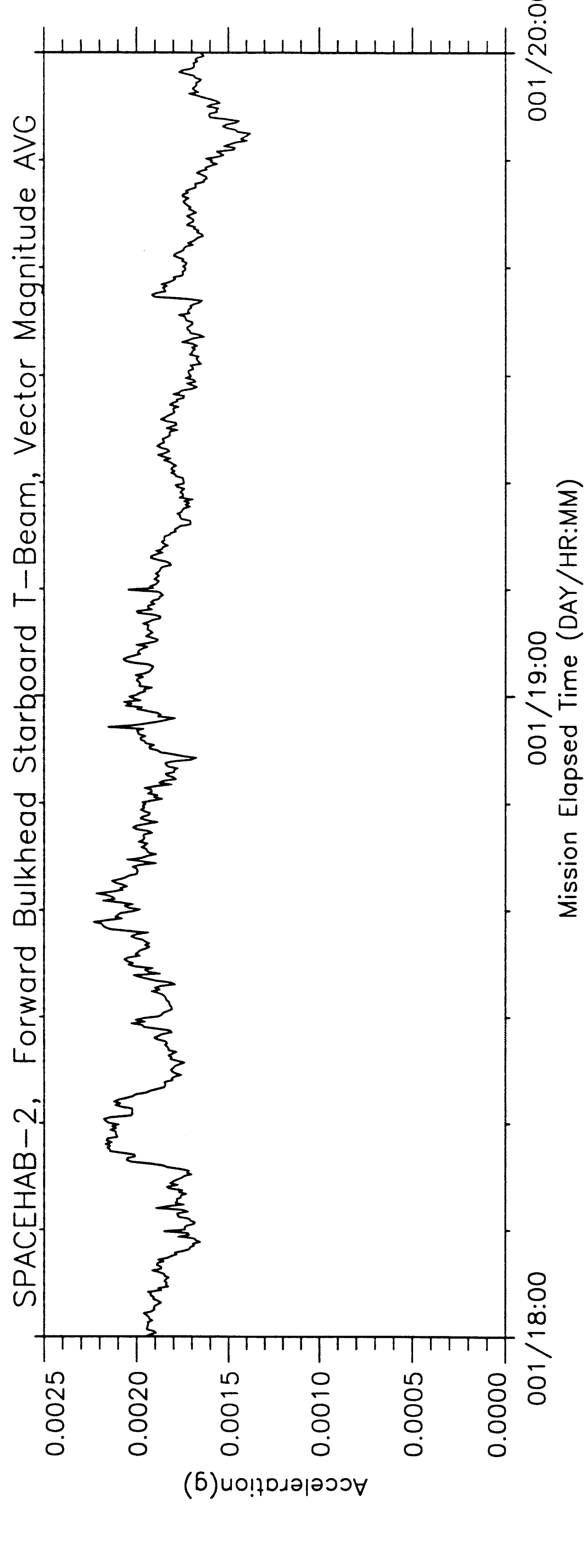
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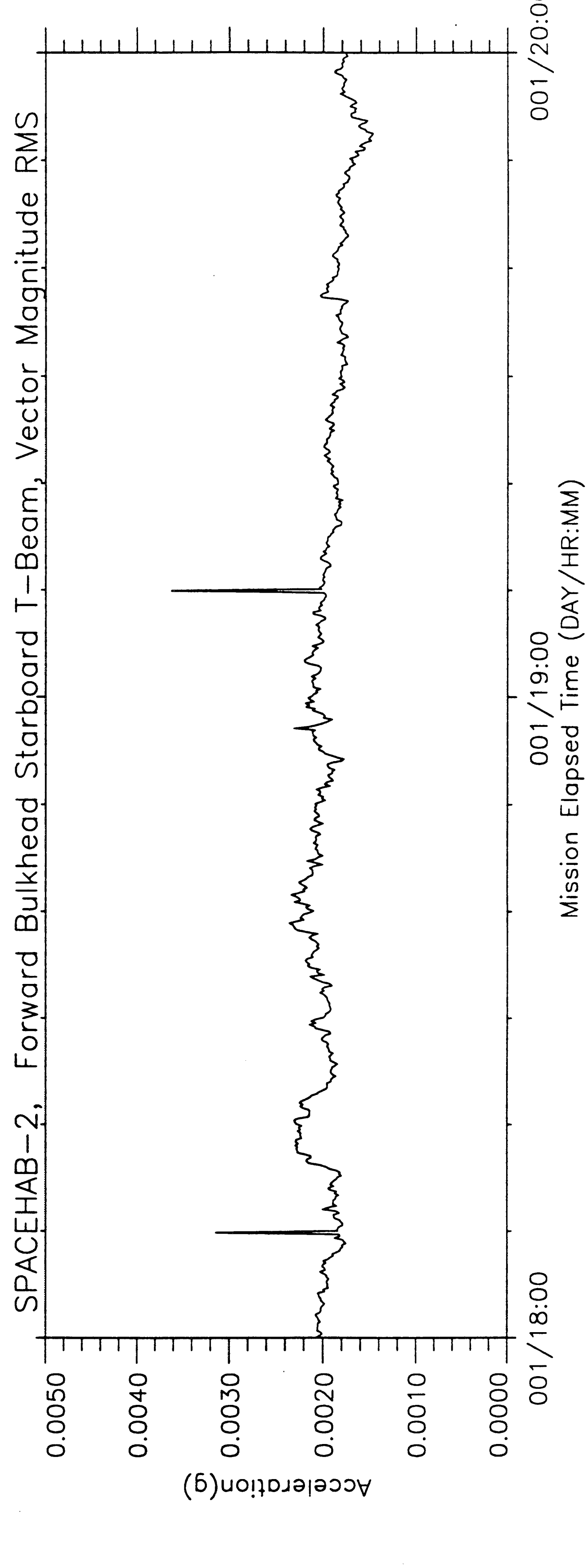
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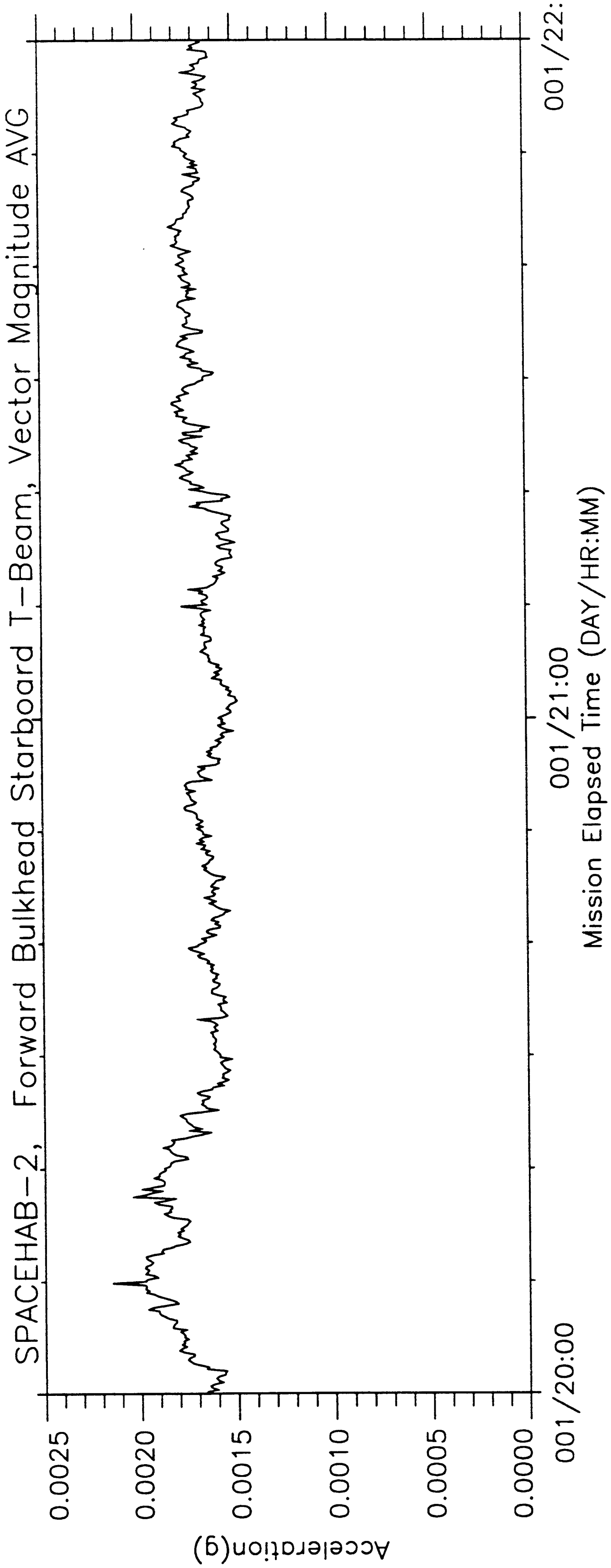
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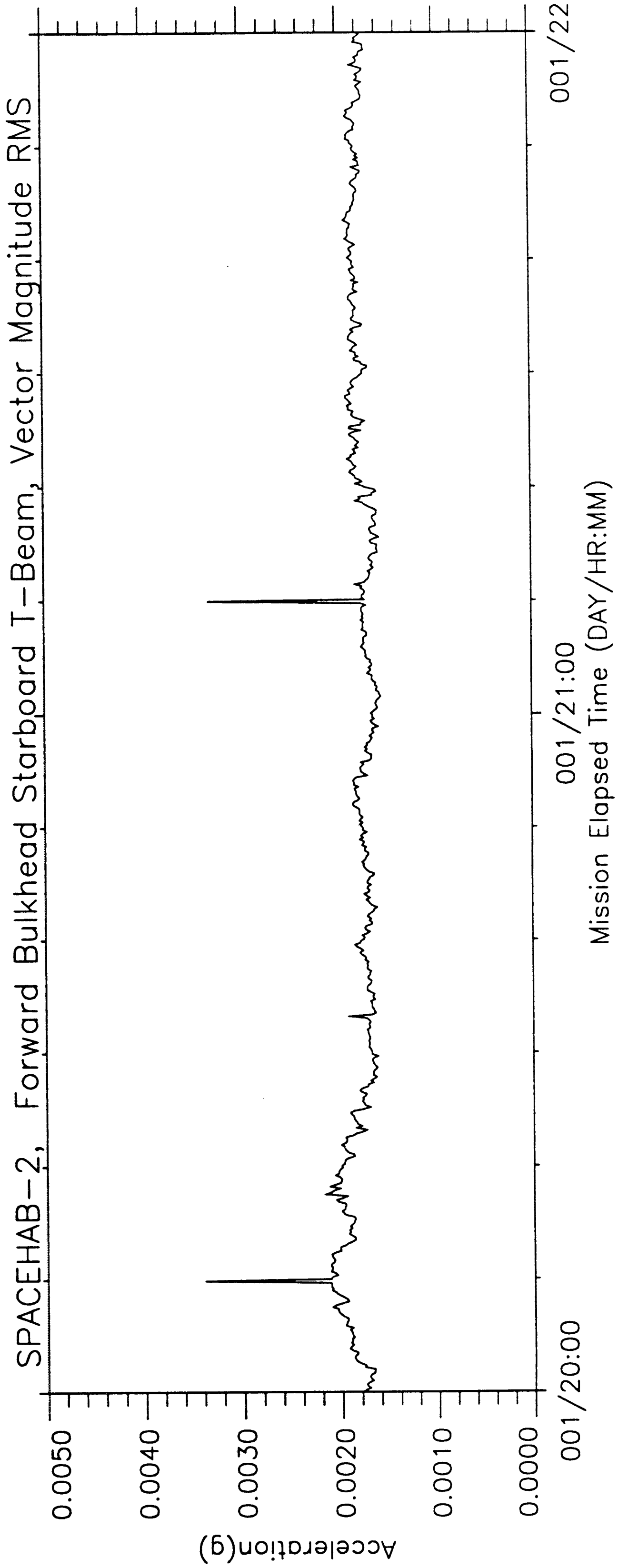
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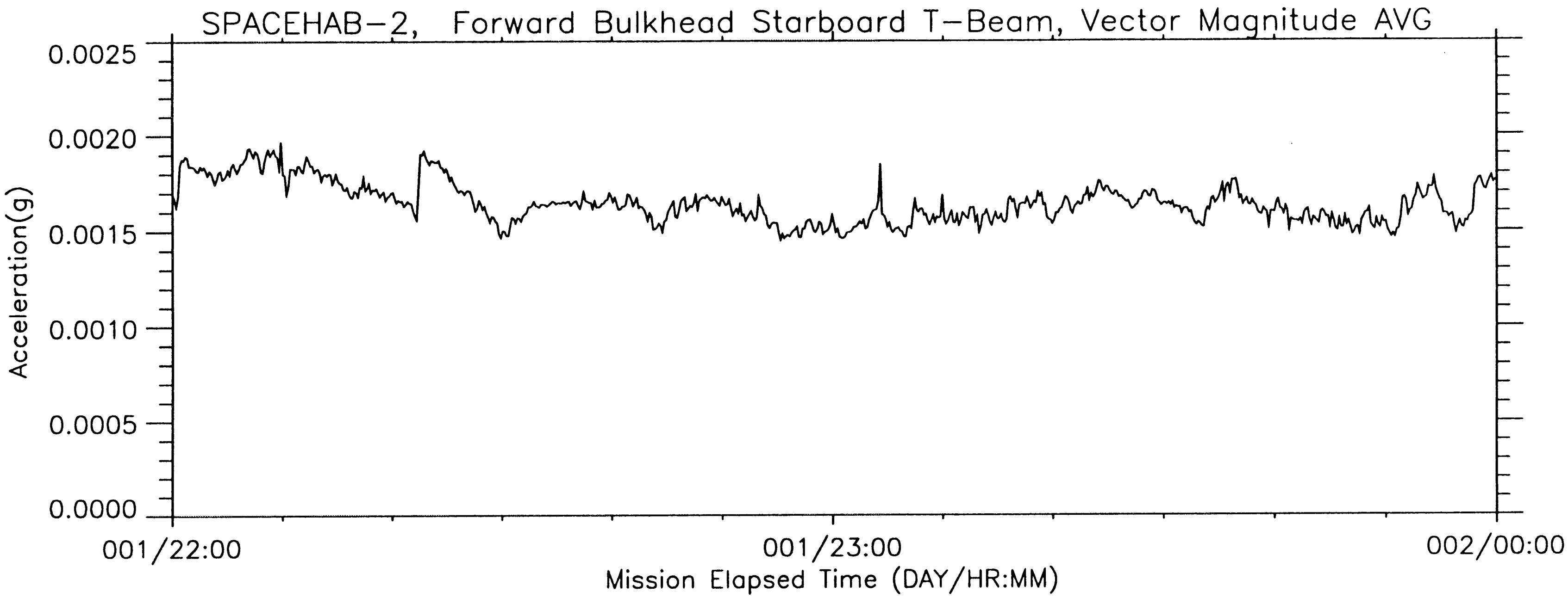
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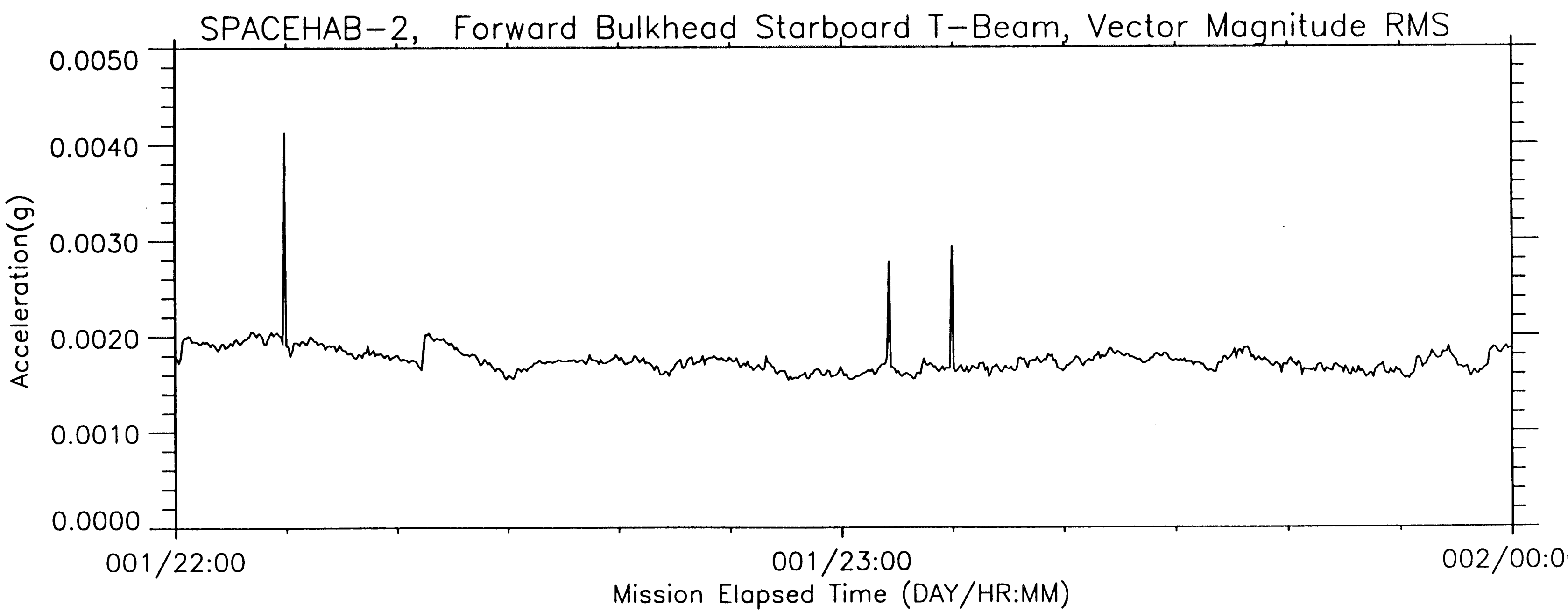
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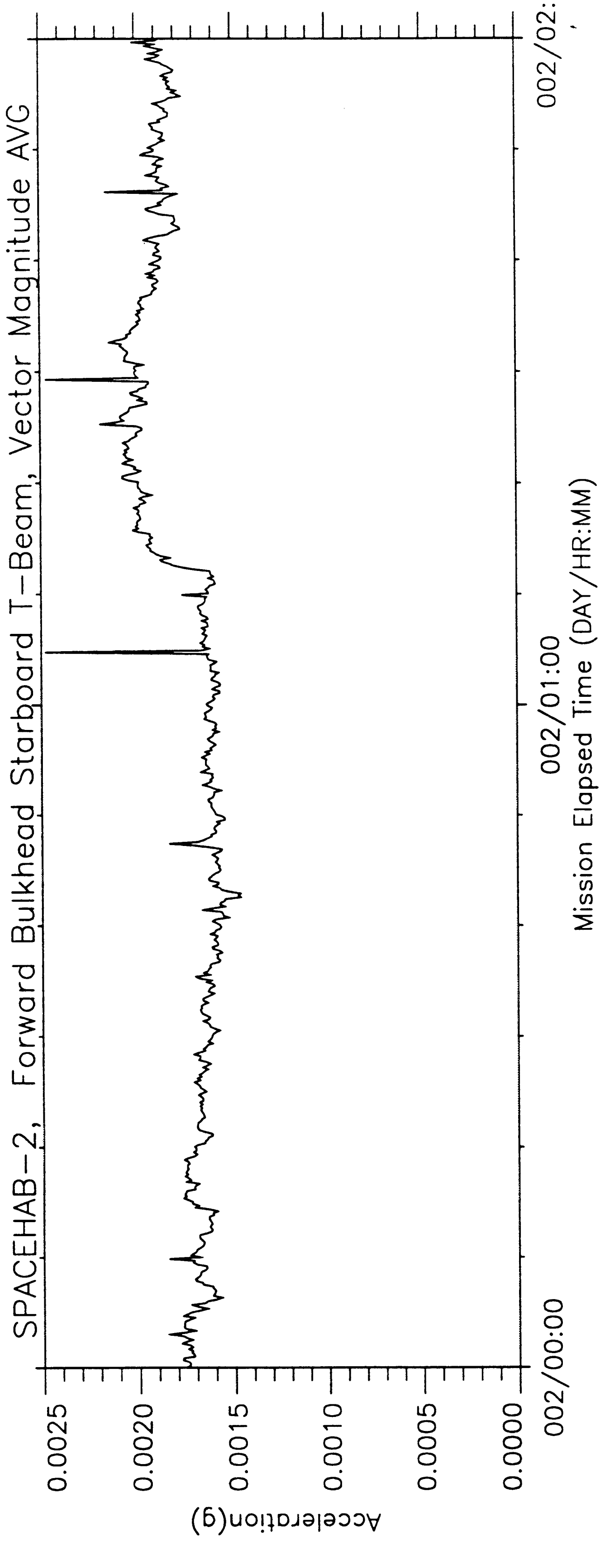
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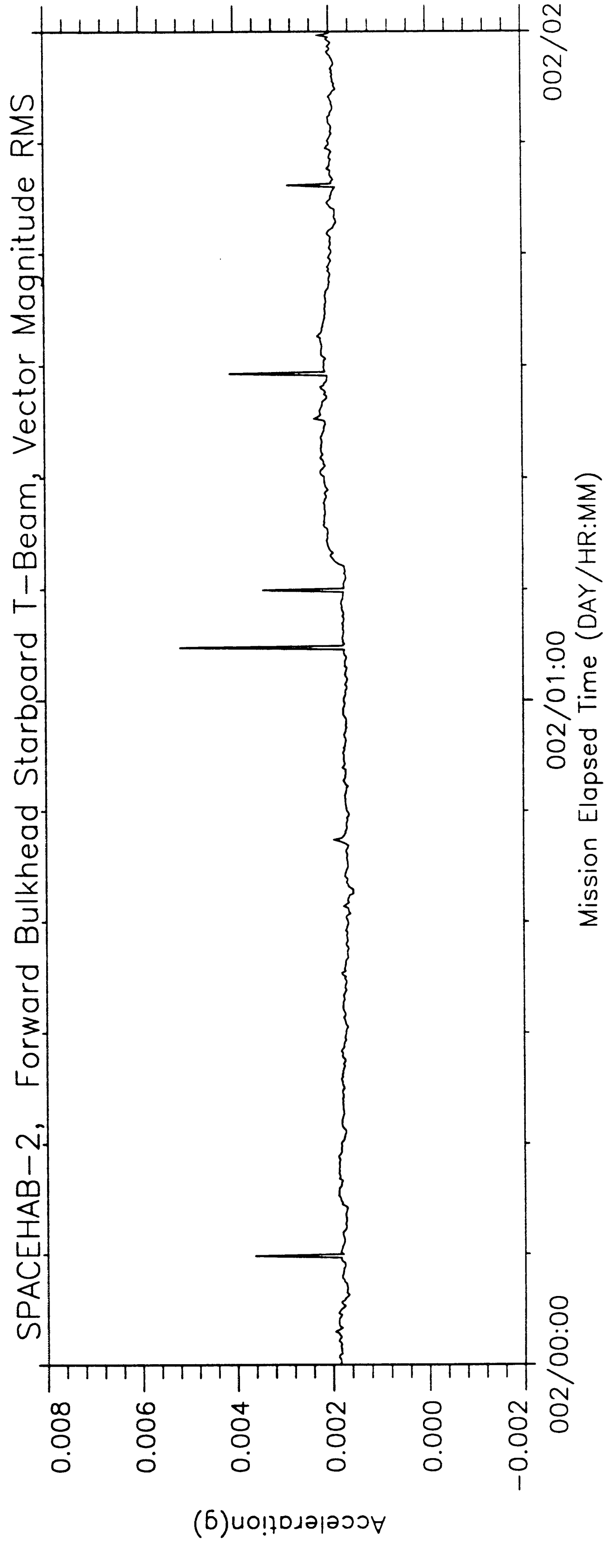
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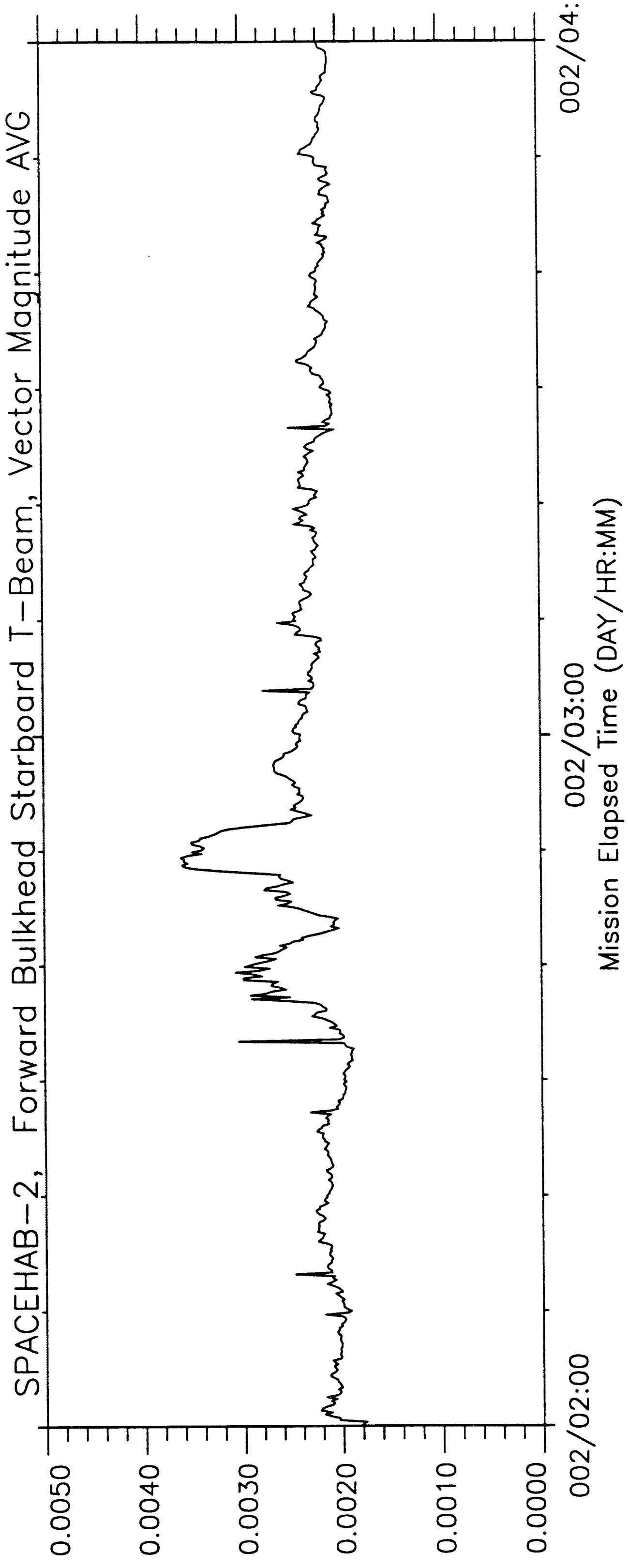
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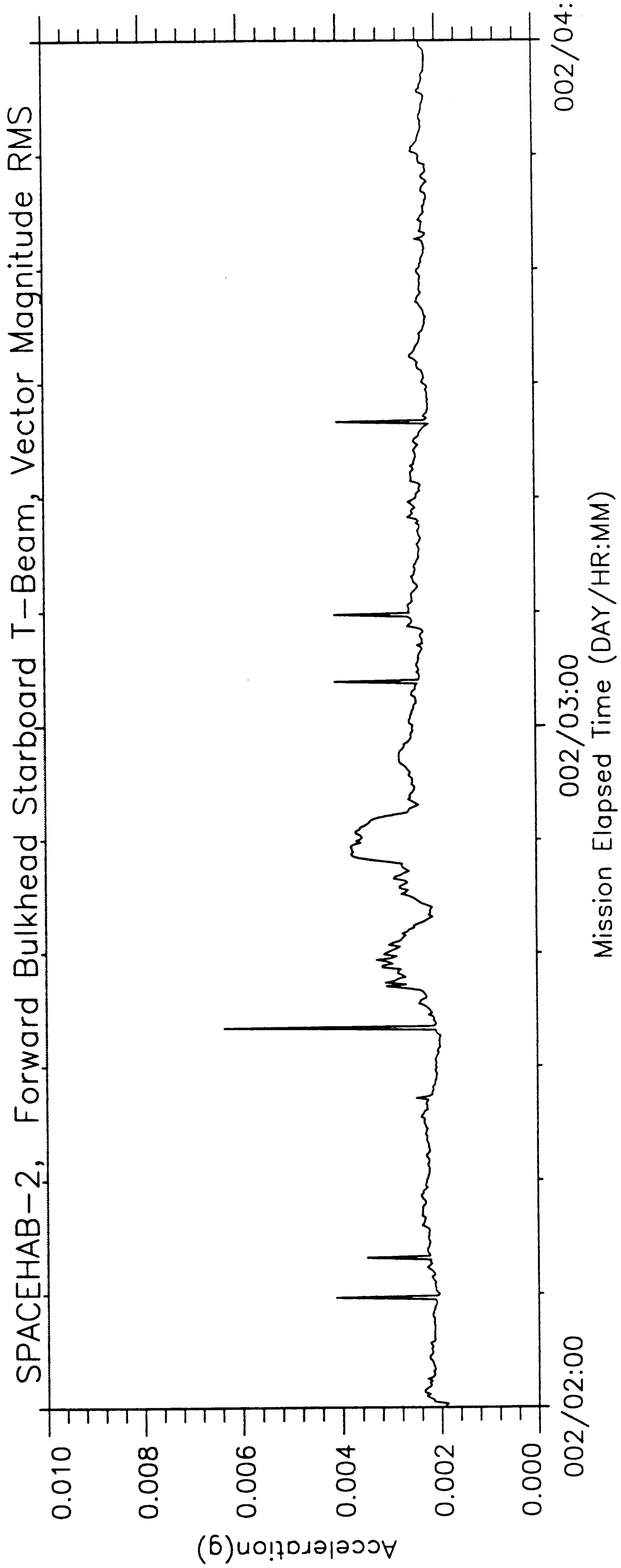
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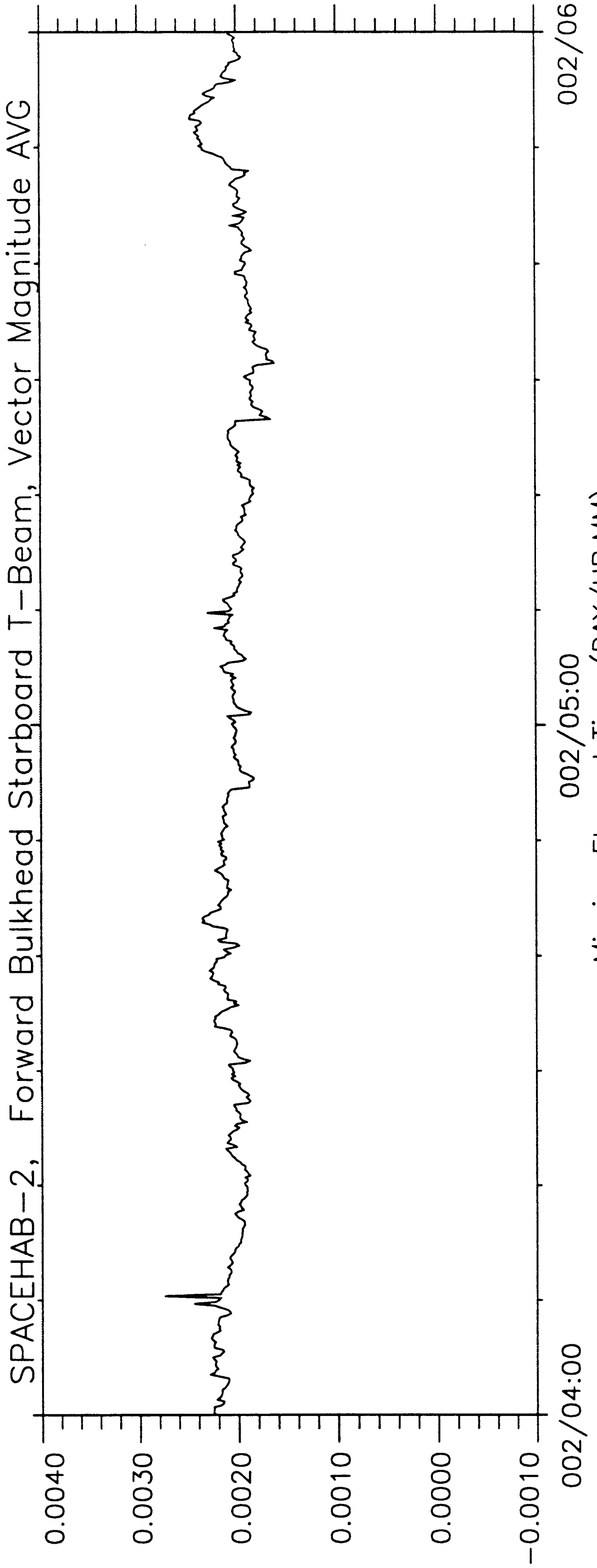
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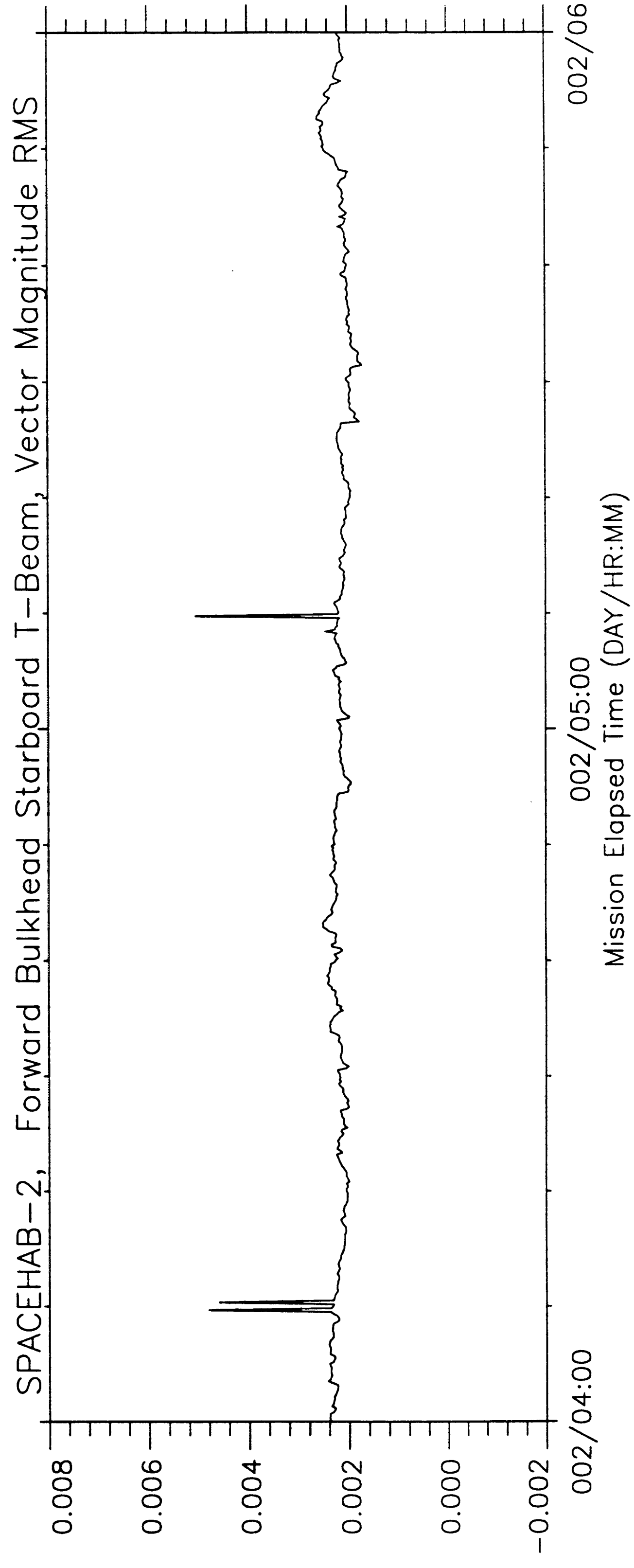
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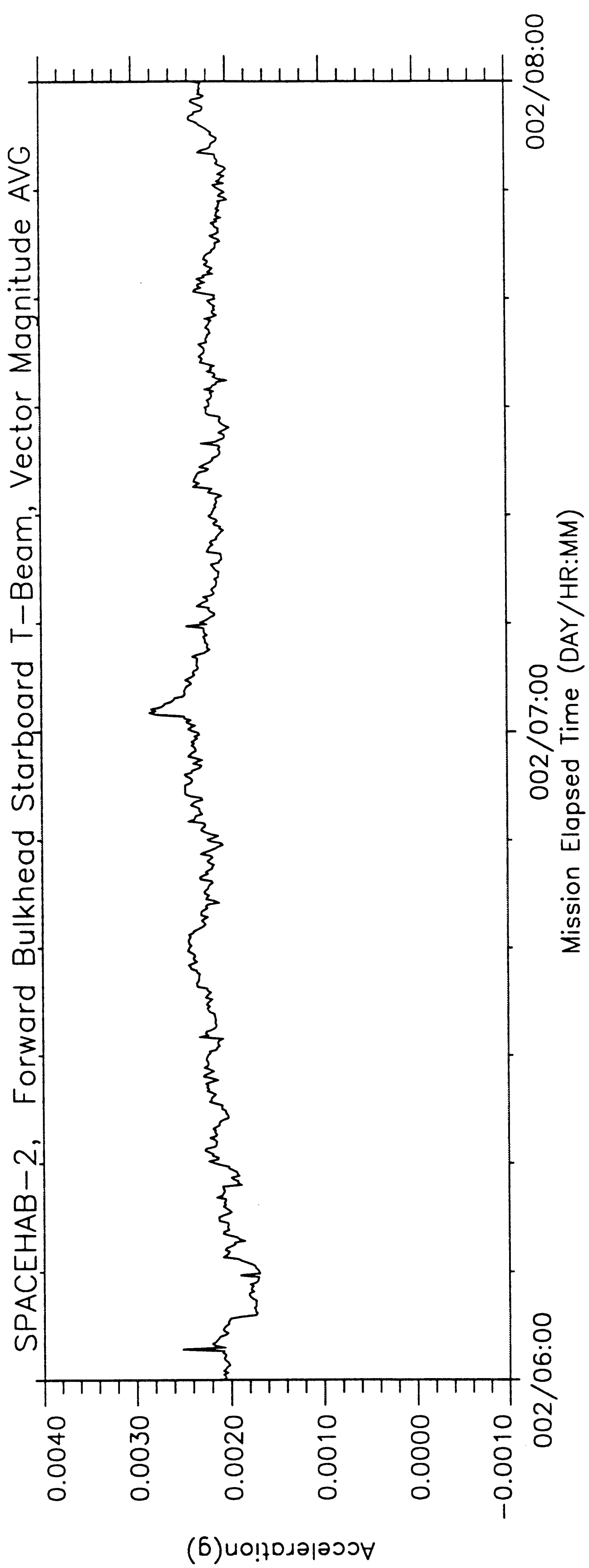
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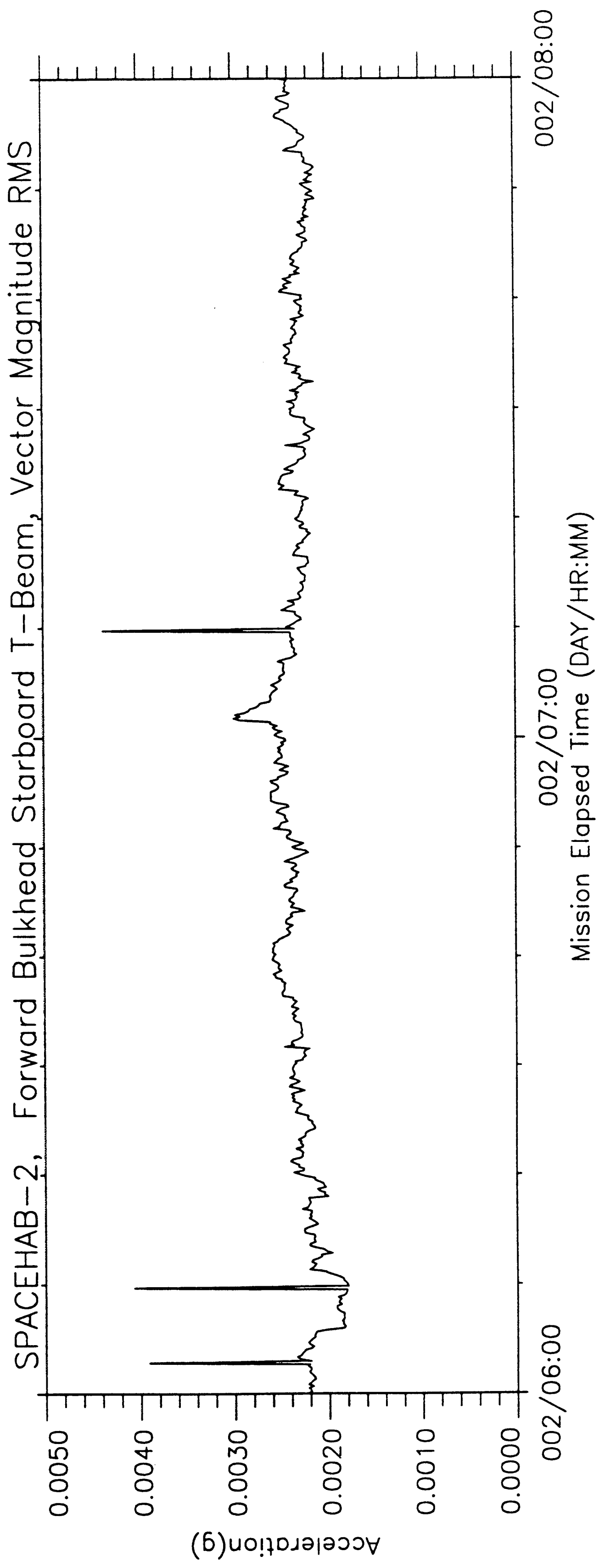
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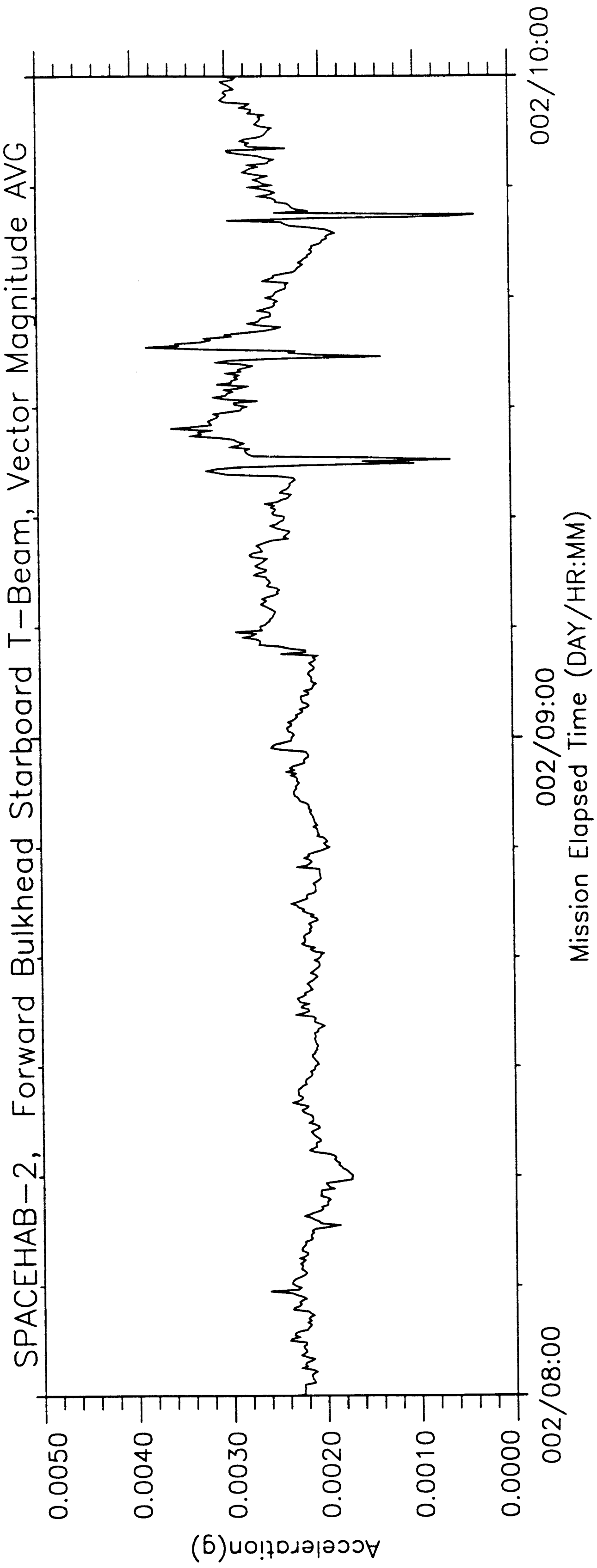
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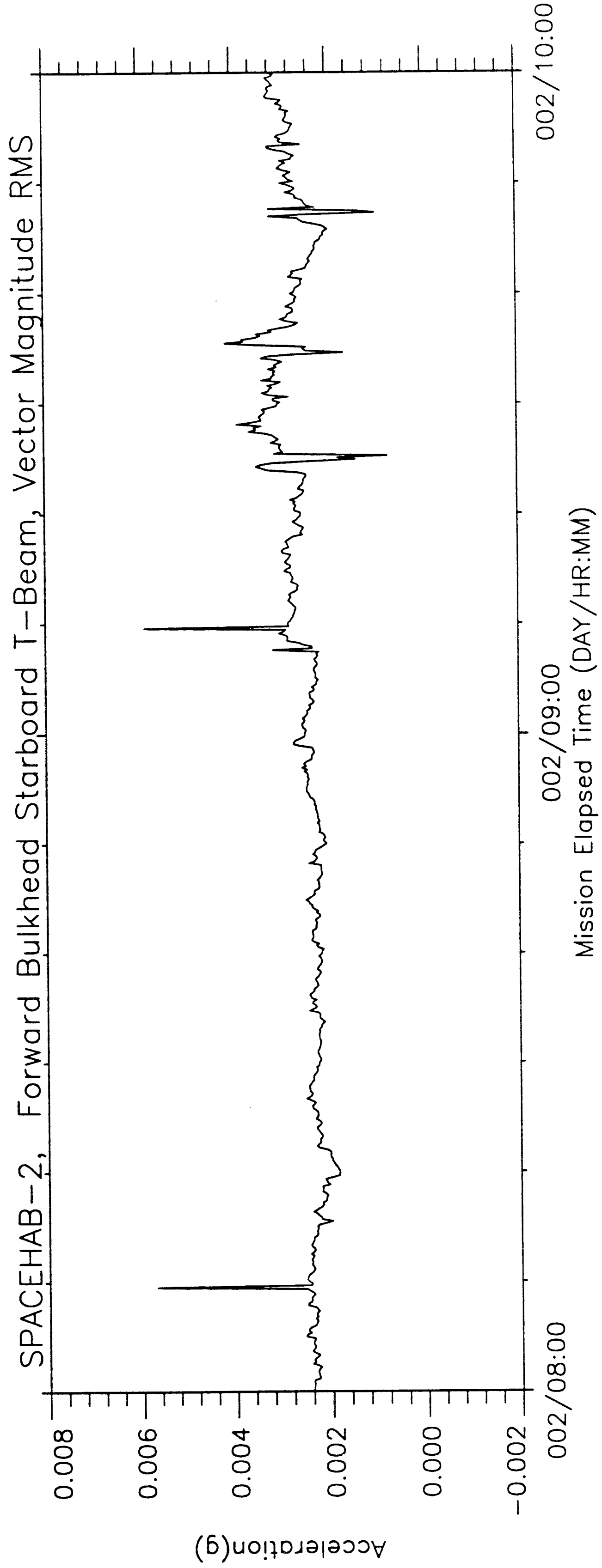
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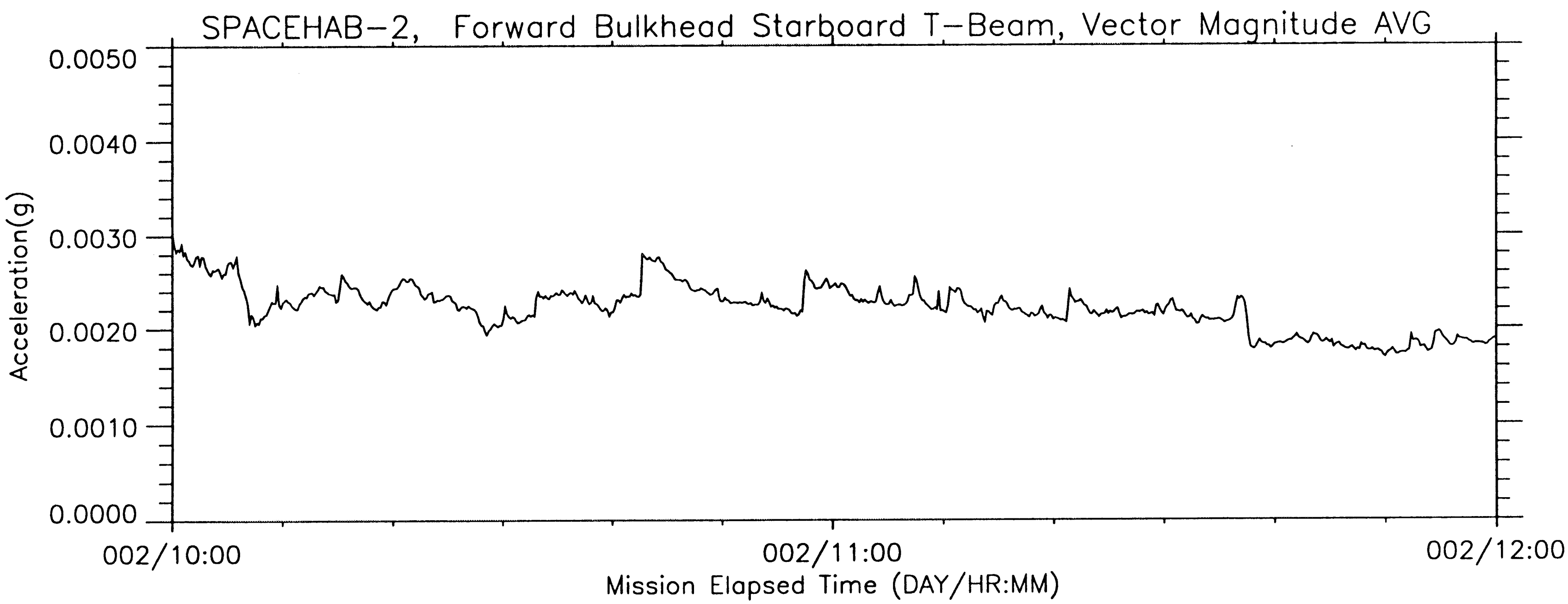
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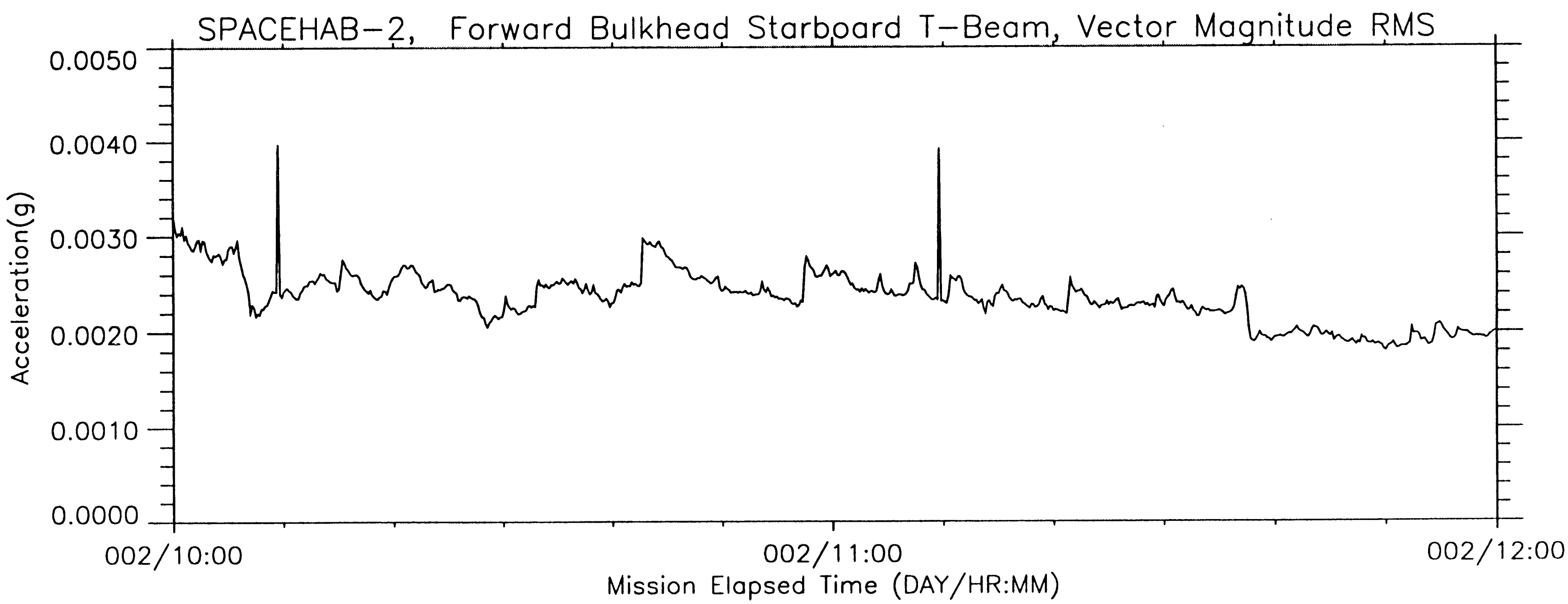
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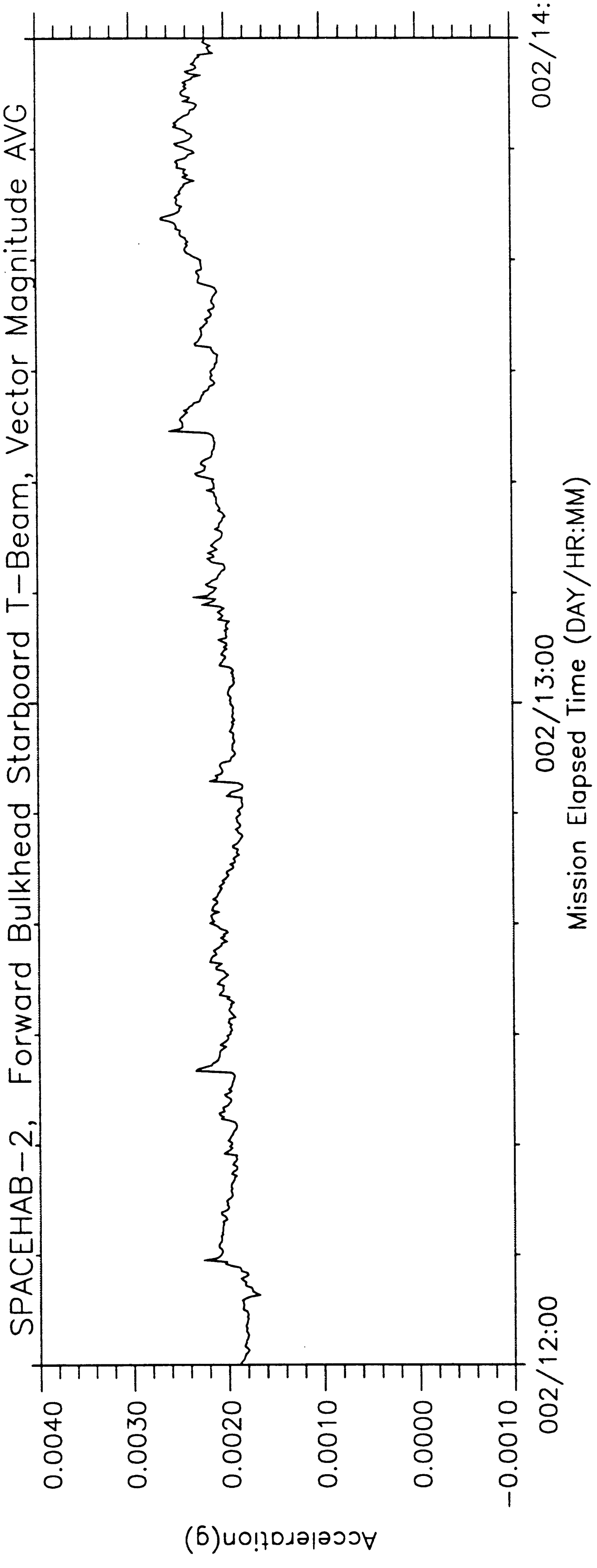
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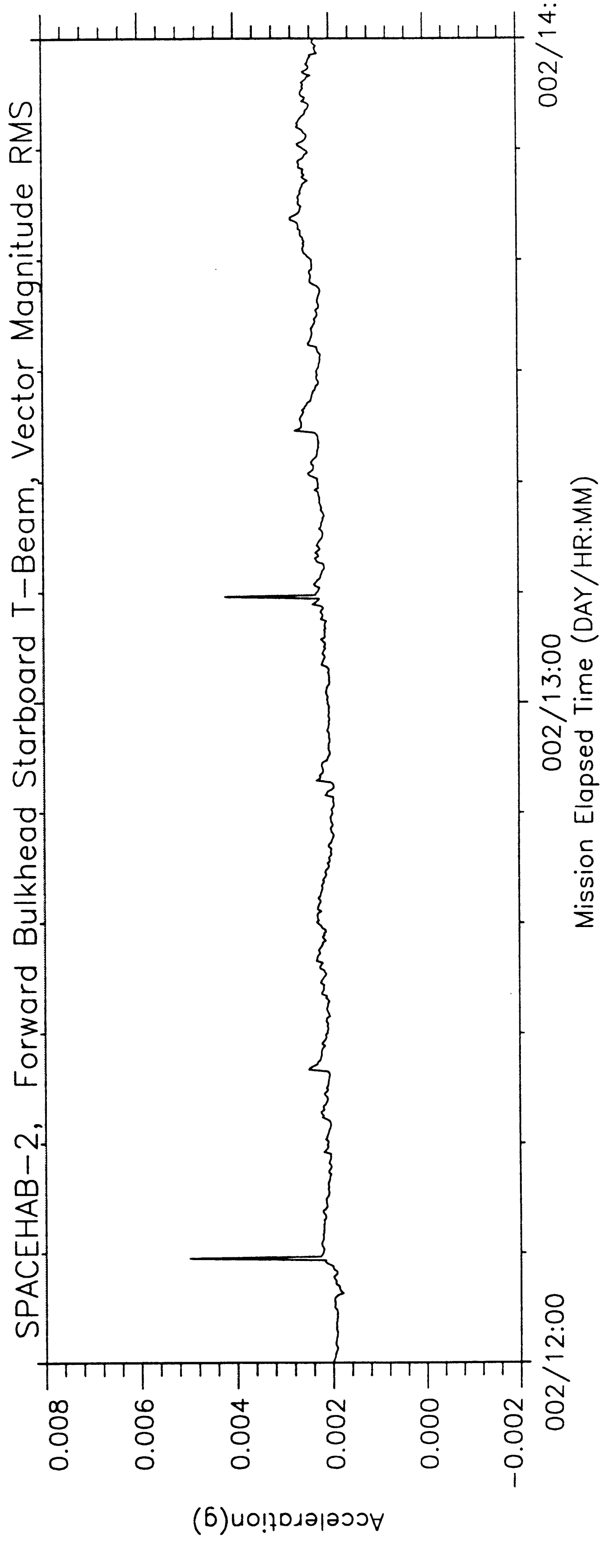
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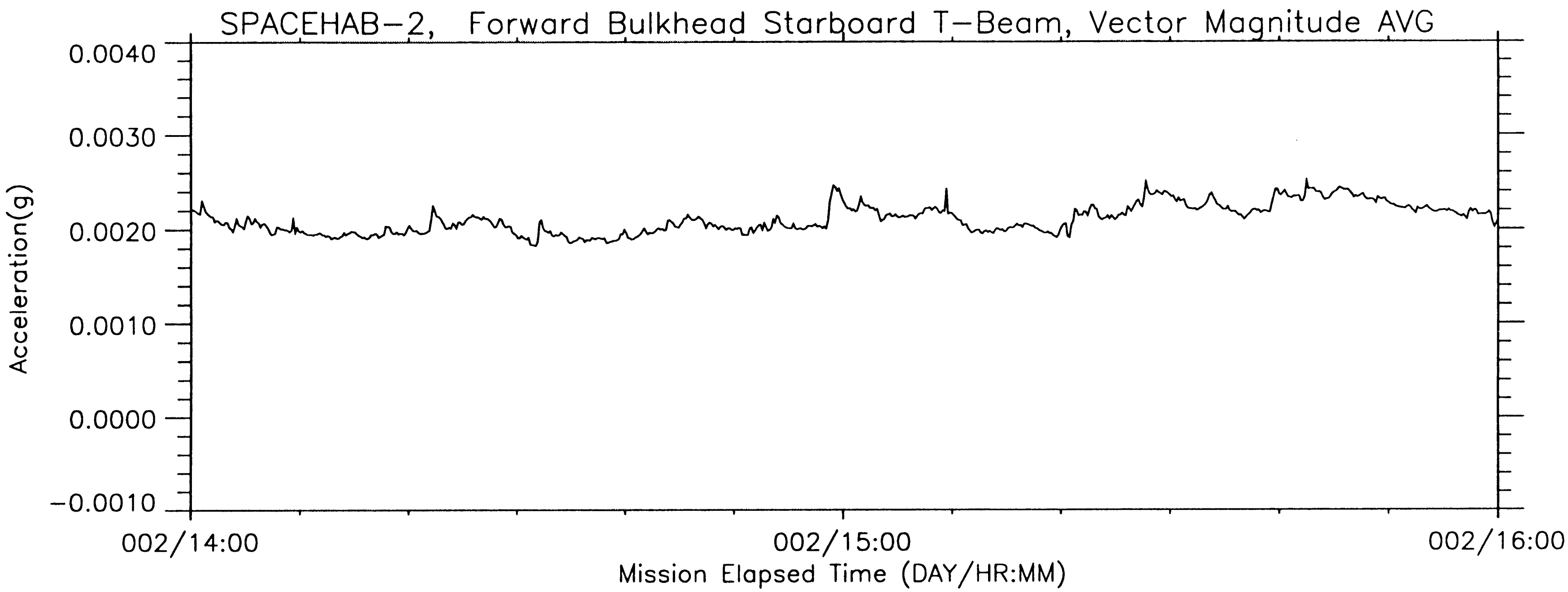

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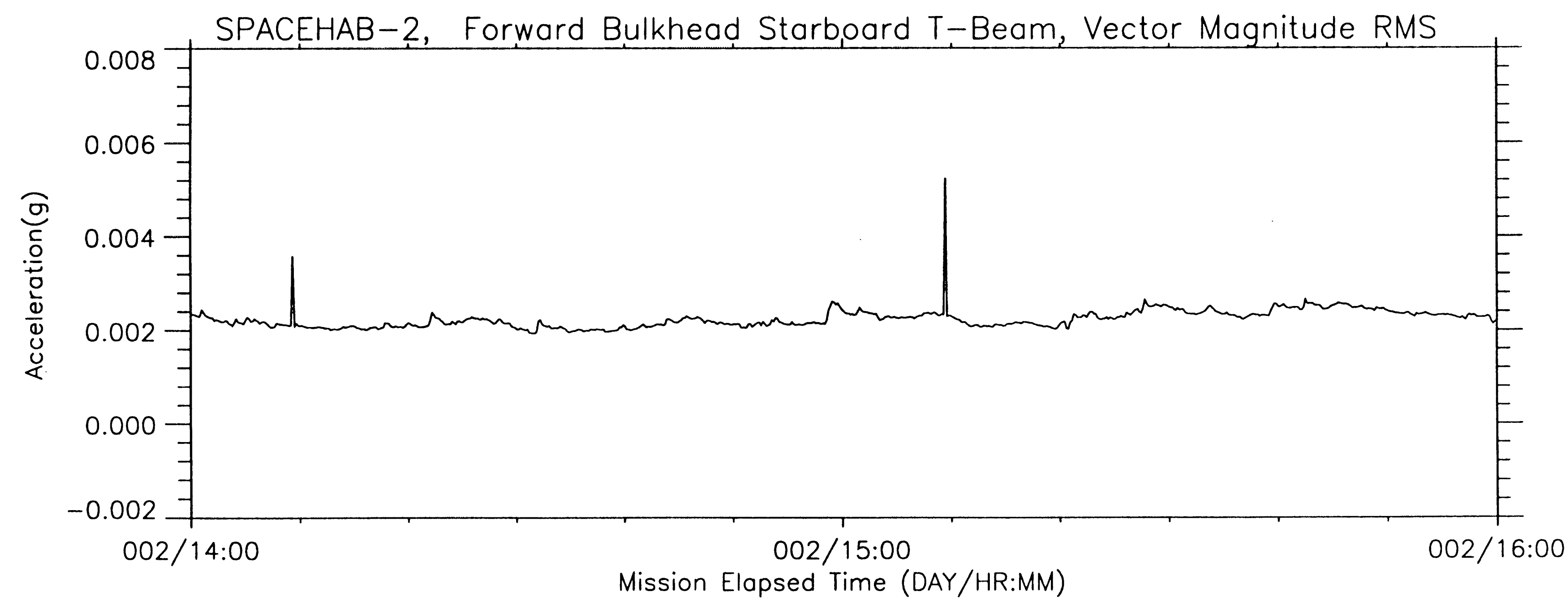

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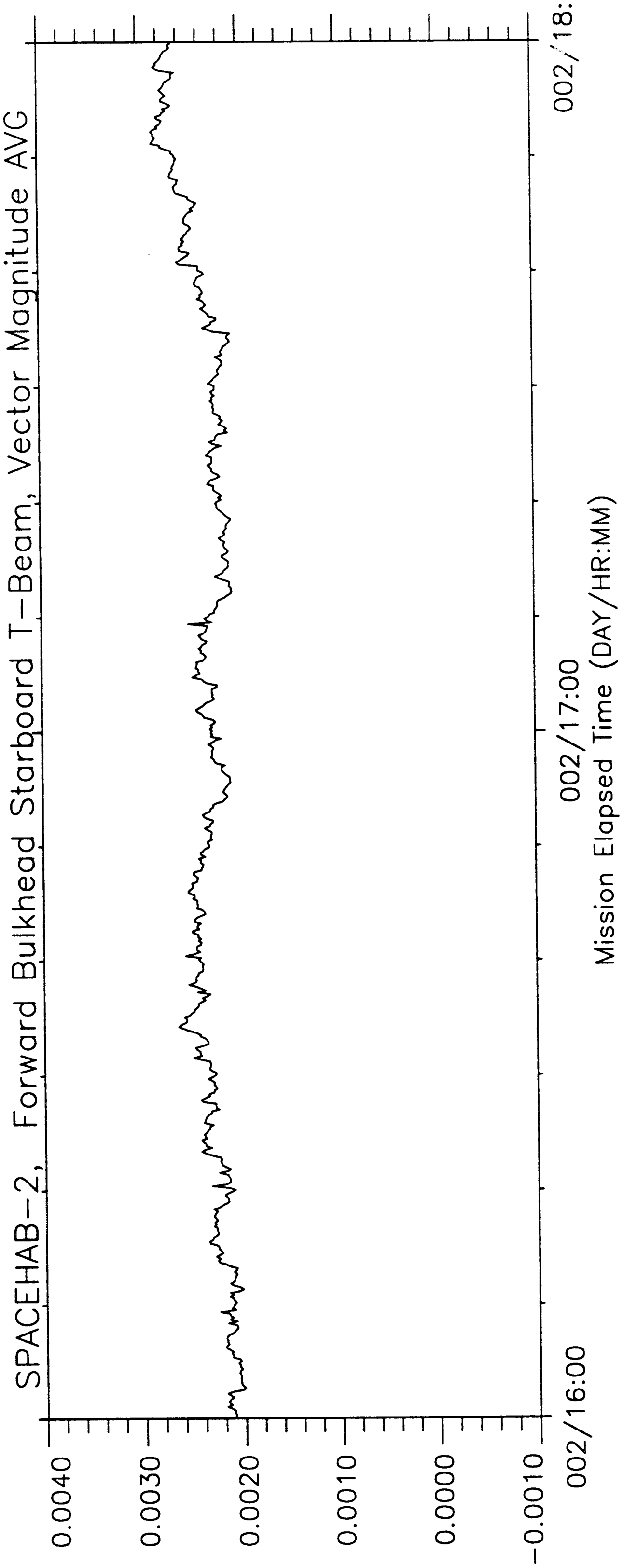
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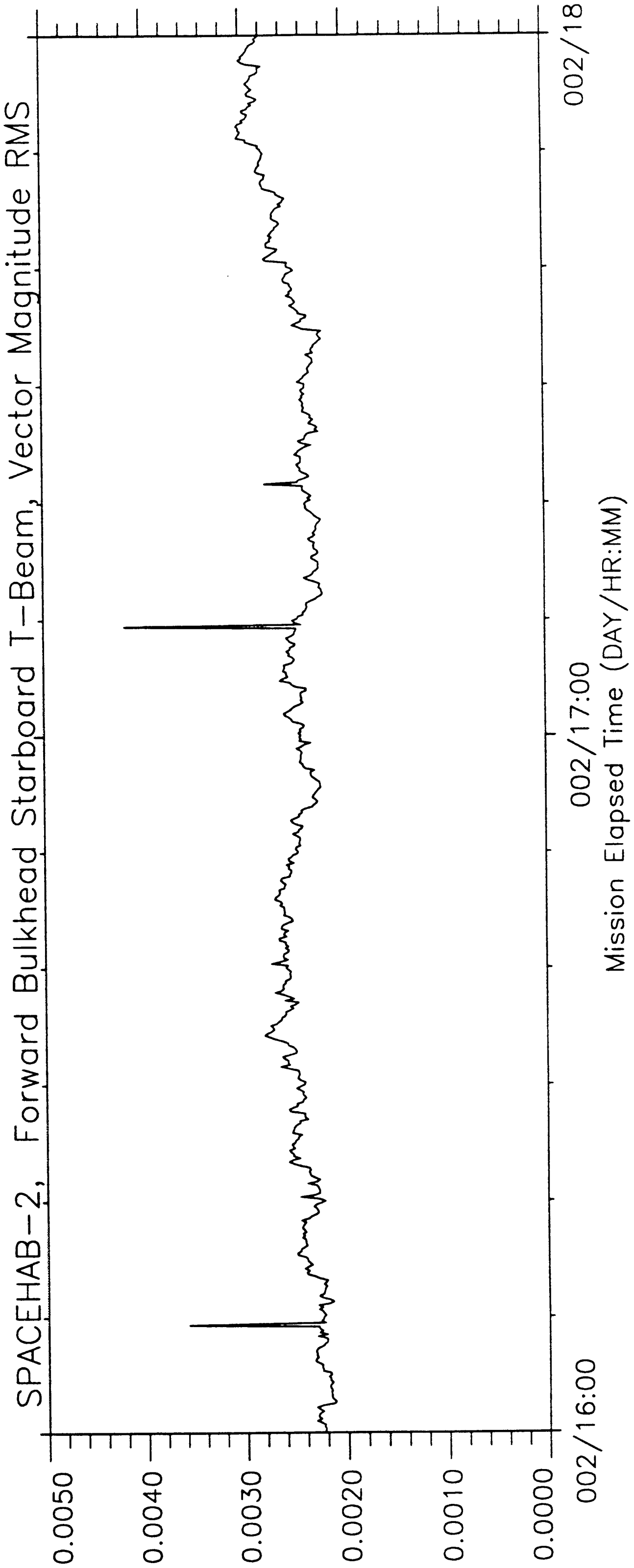
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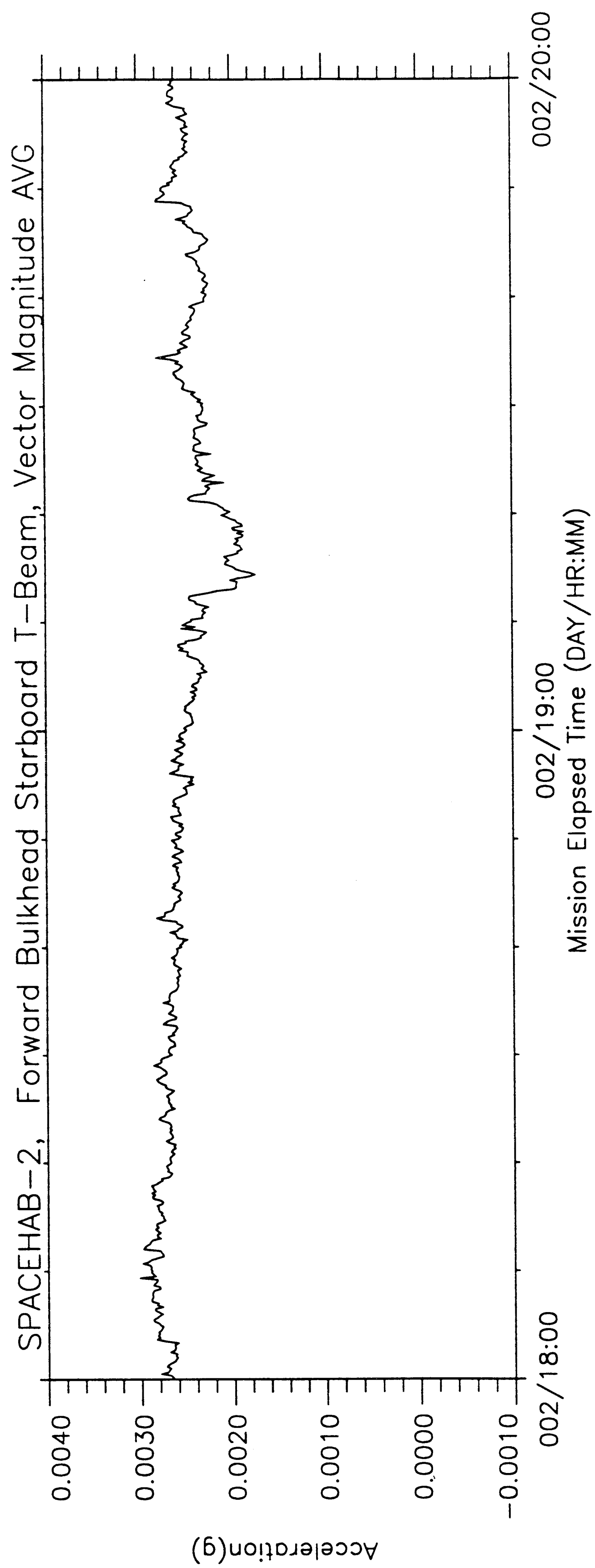
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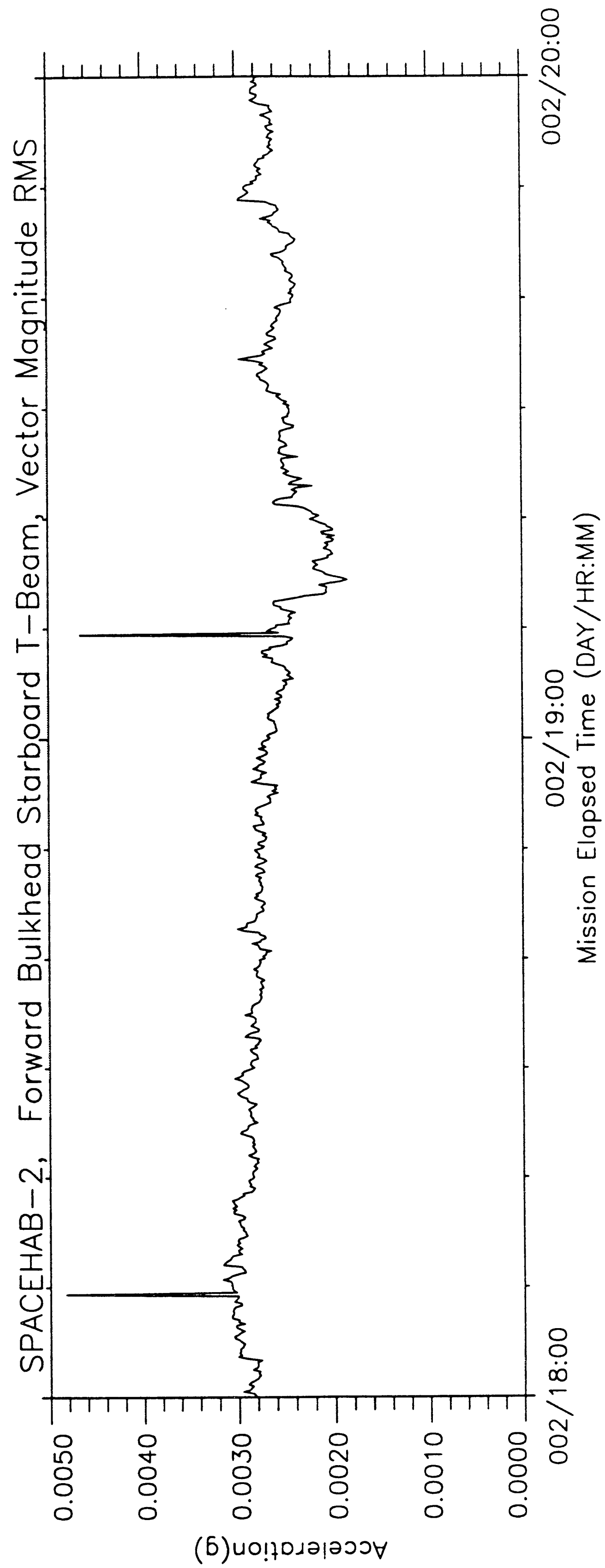
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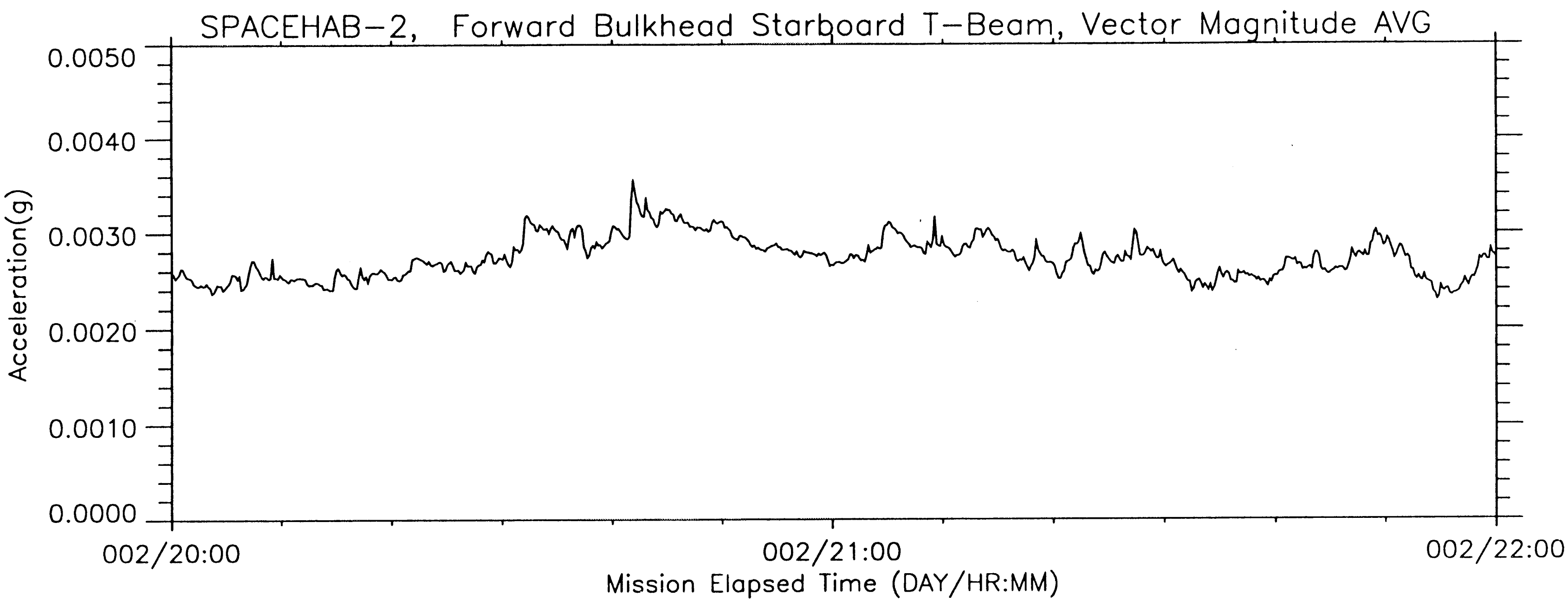
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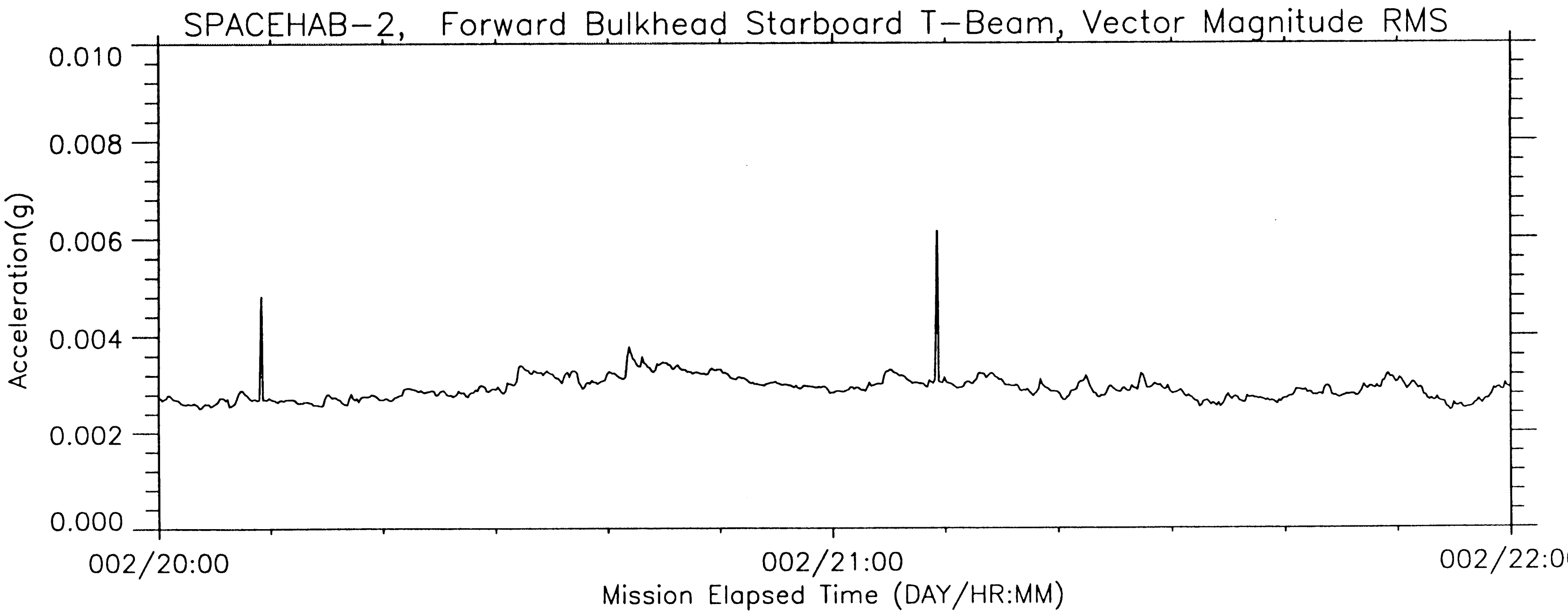
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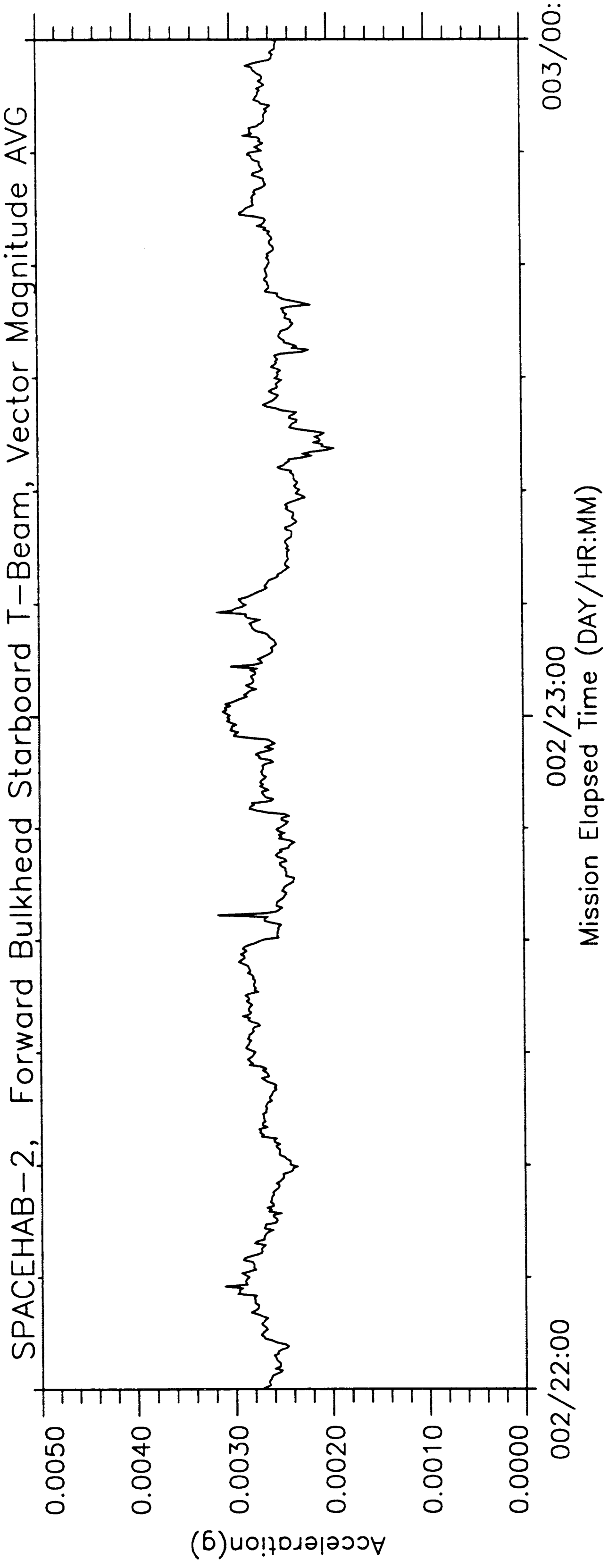
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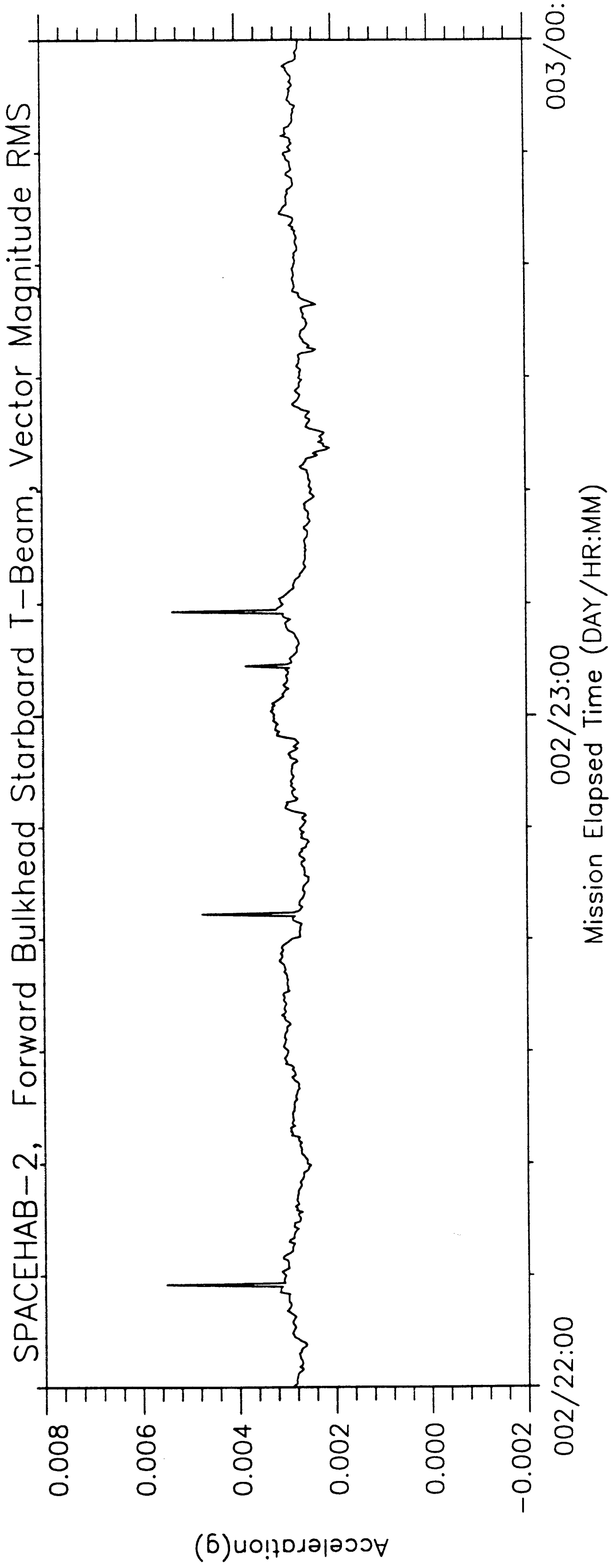
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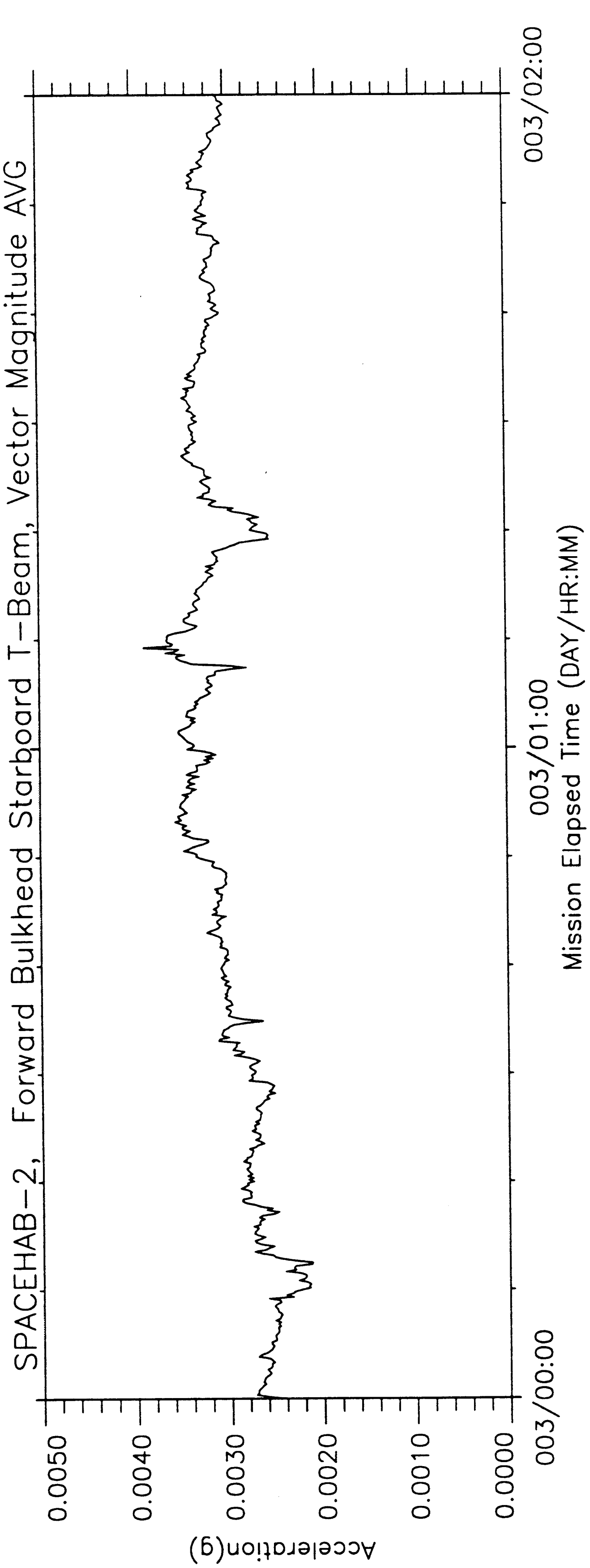
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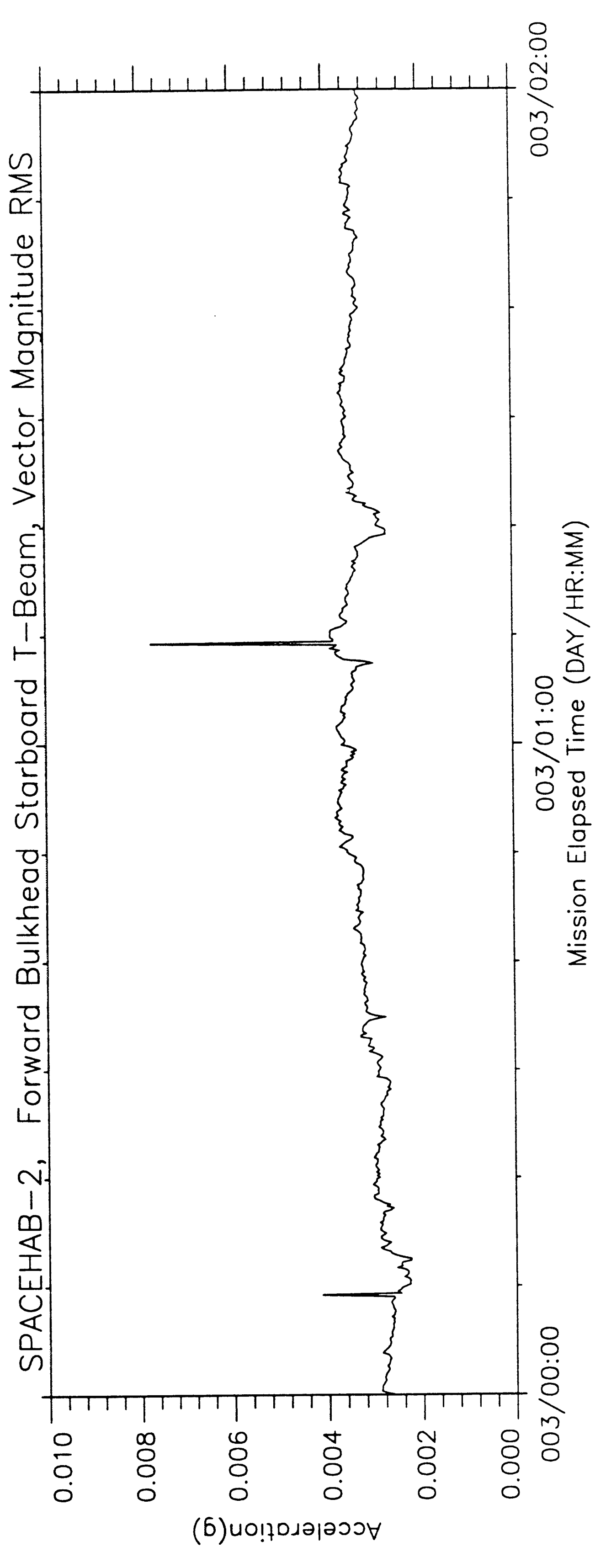
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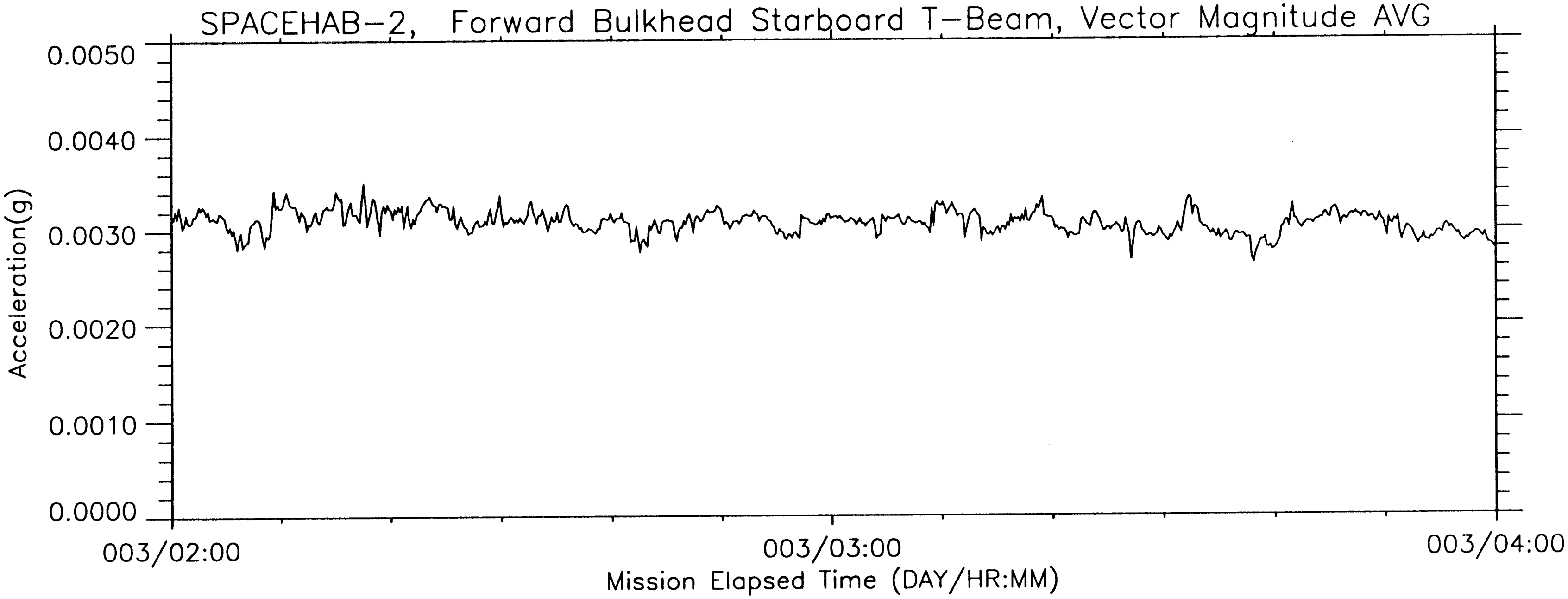
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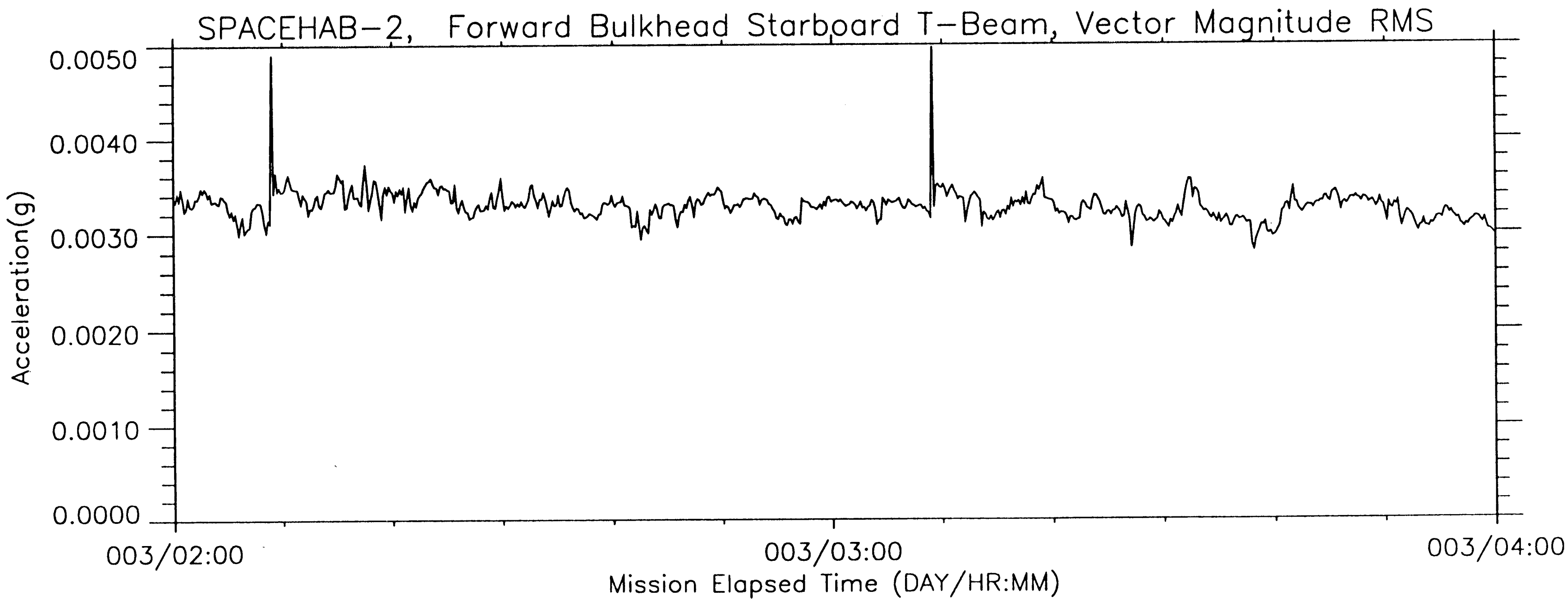
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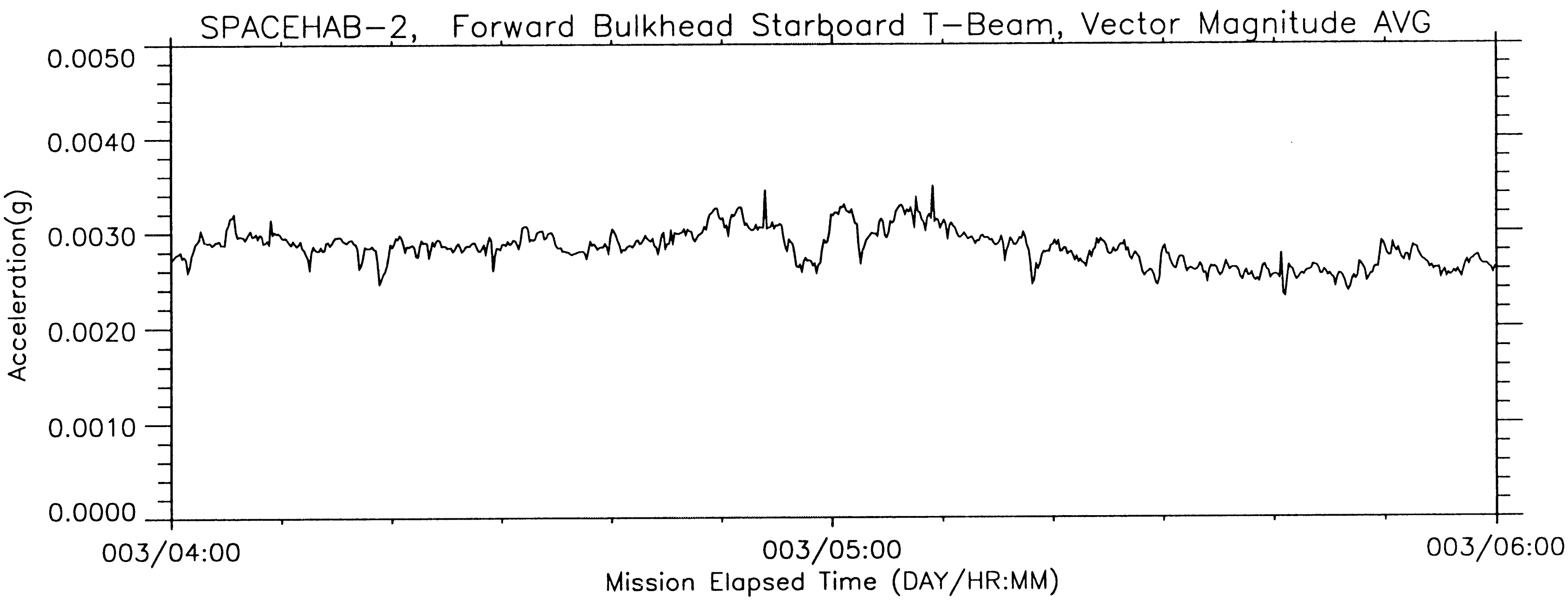
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Acceleration(g)
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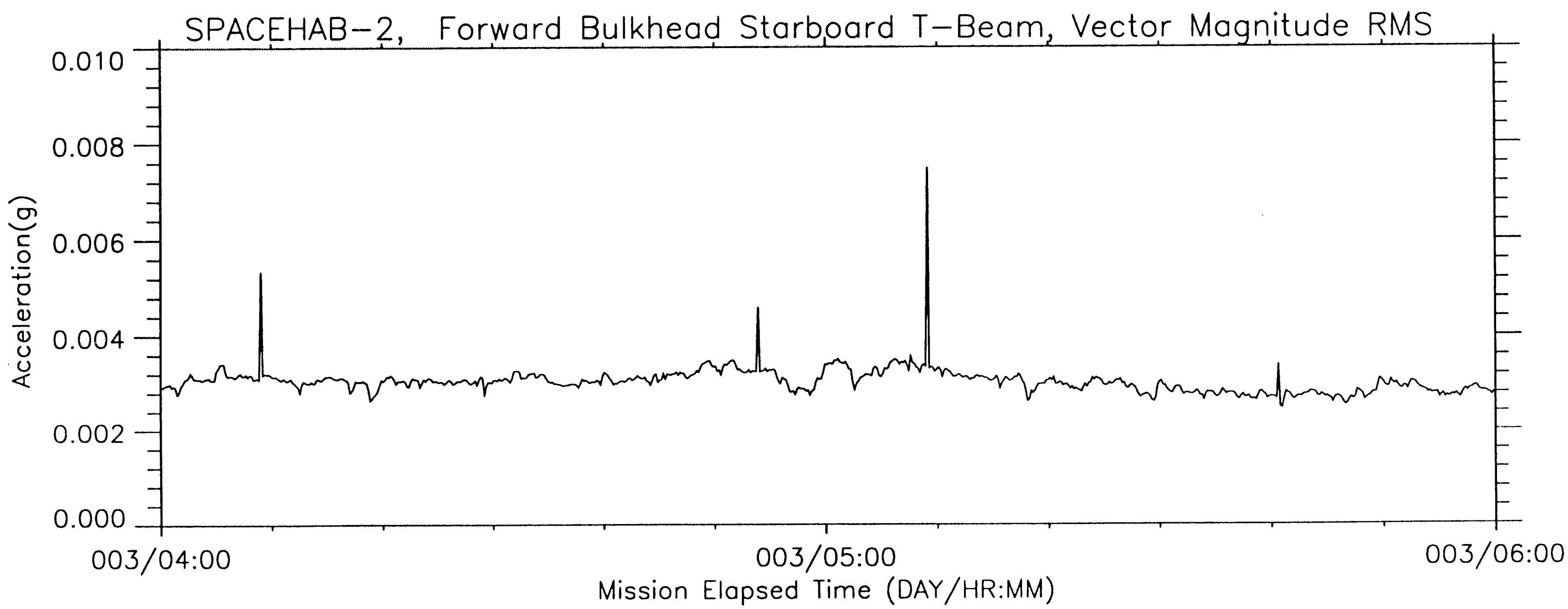
003/06:00
Mission Elapsed Time (DAY/HR:MM)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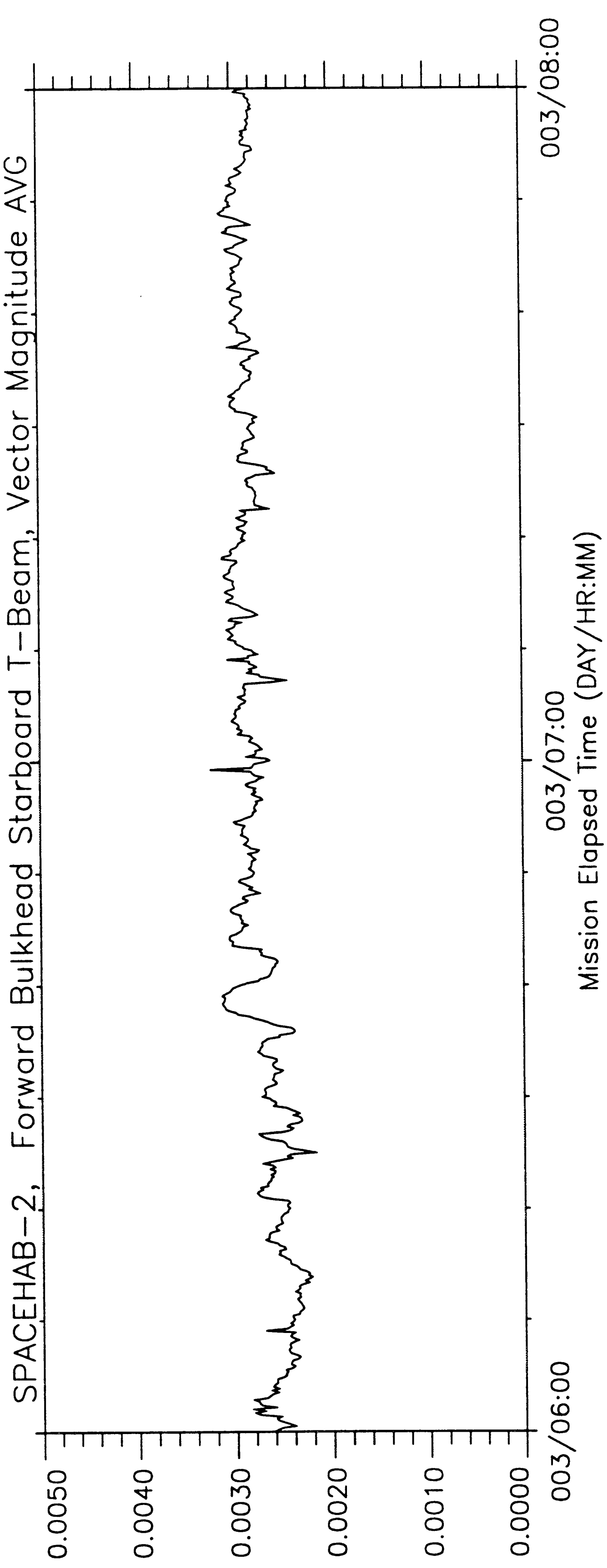
Mission Elapsed Time (DAY/HR:MM)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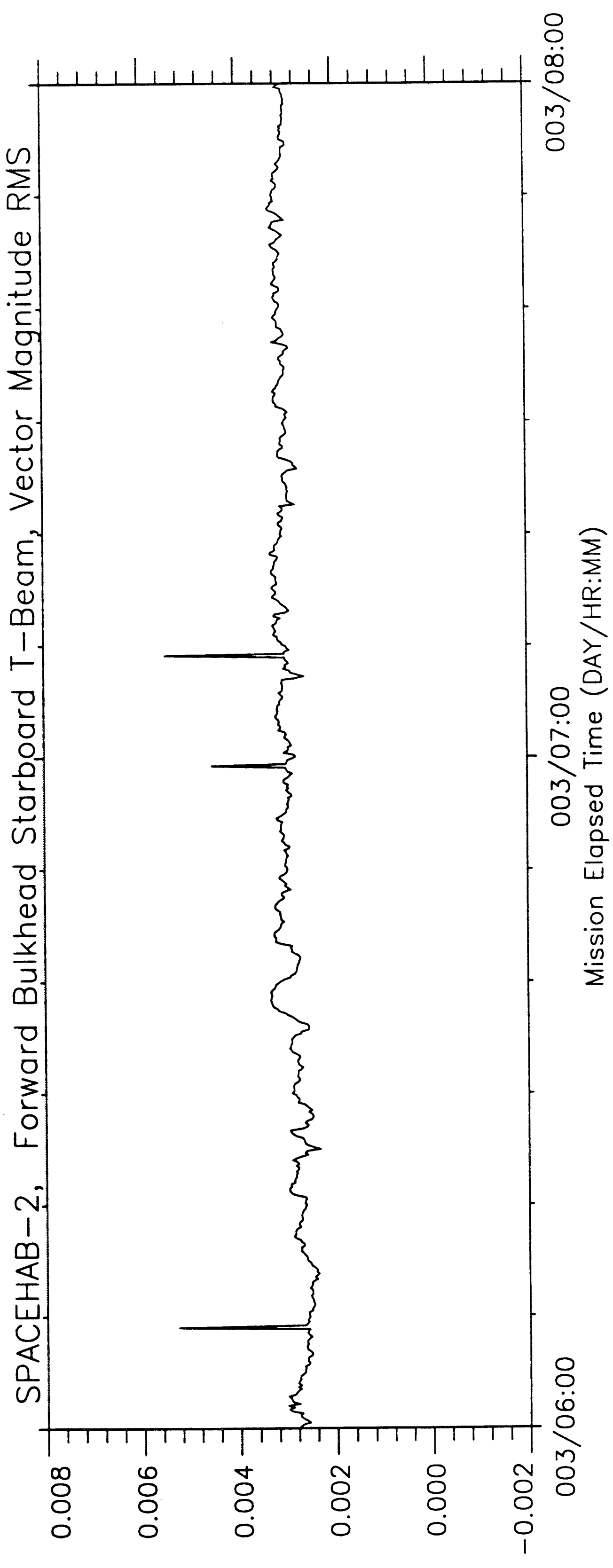
003/08:00
Mission Elapsed Time (DAY/HR:MM)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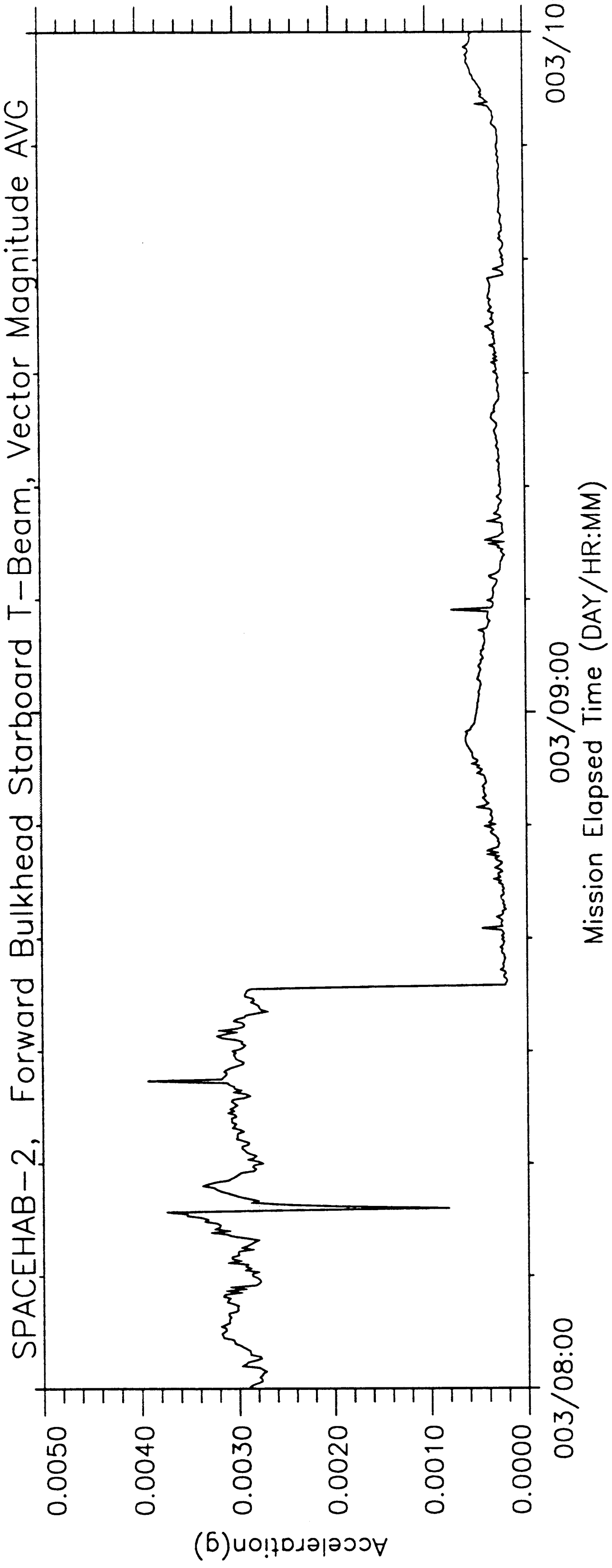
003/08:00
Mission Elapsed Time (DAY/HR:MM)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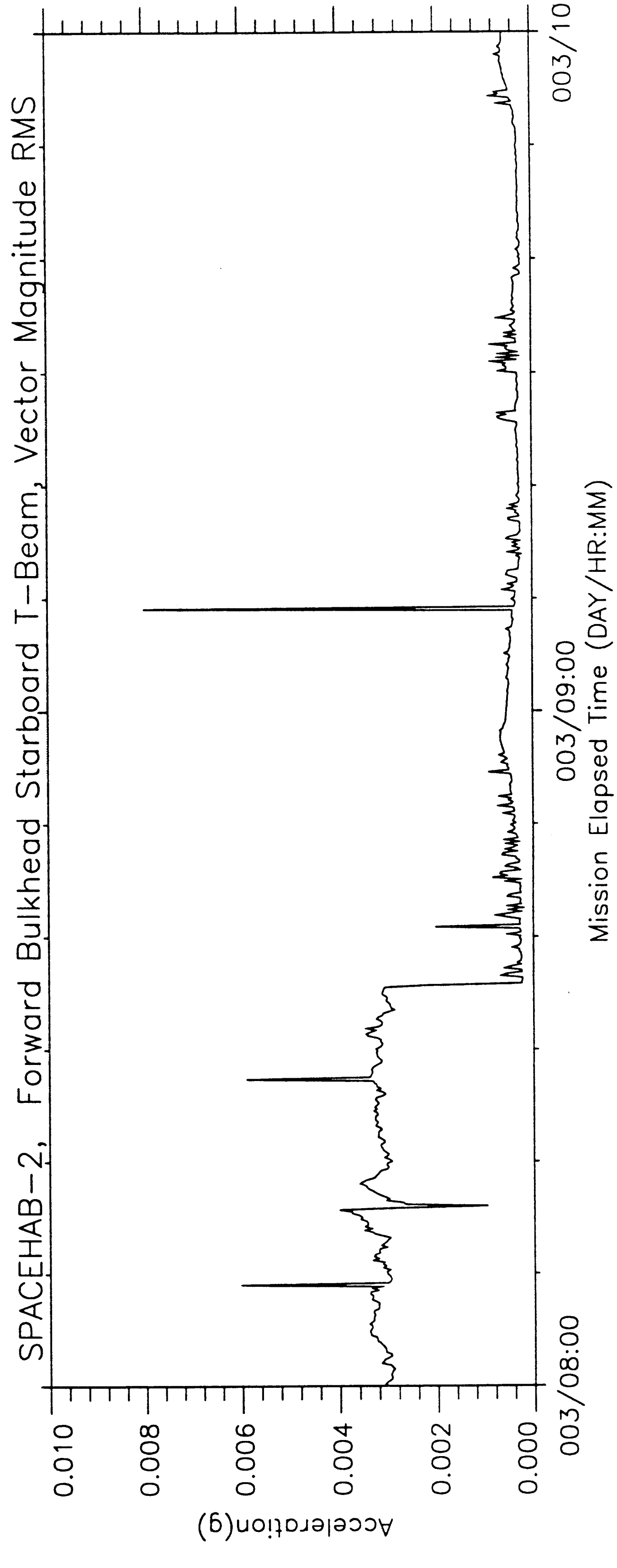
Mission Elapsed Time (DAY/HR:MM)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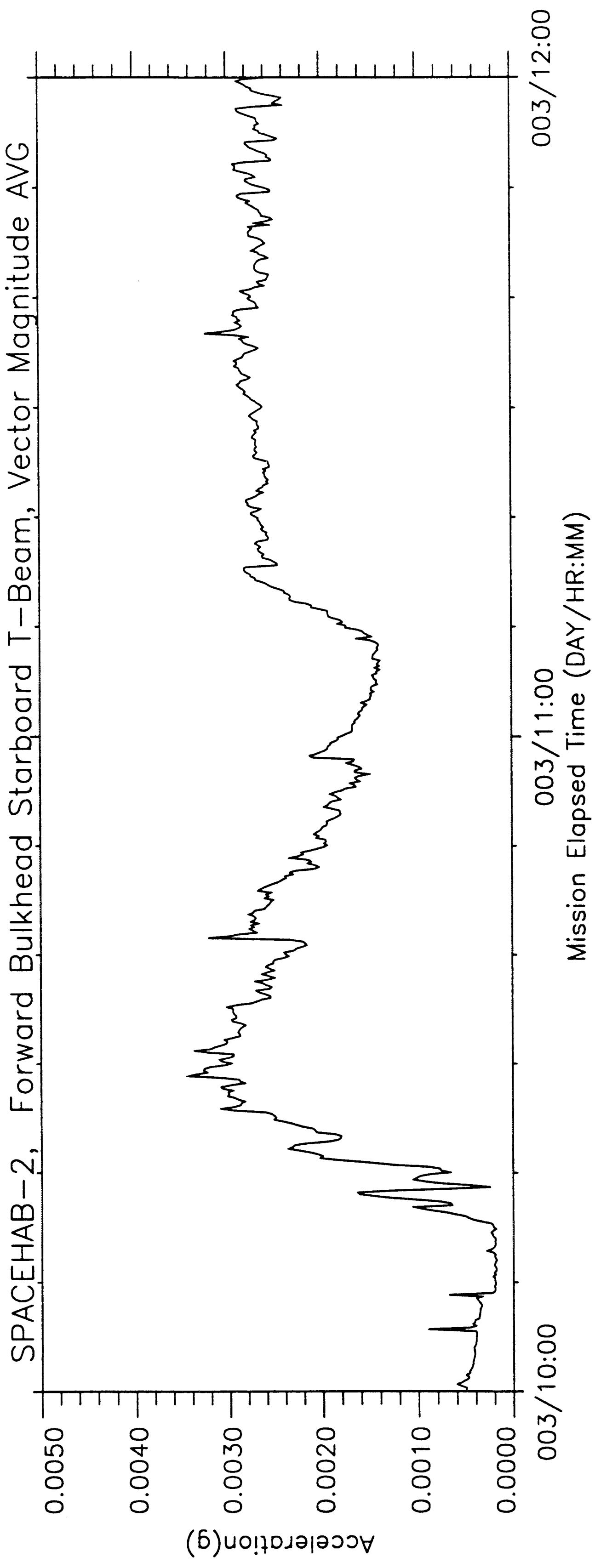
Mission Elapsed Time (DAY/HR:MM)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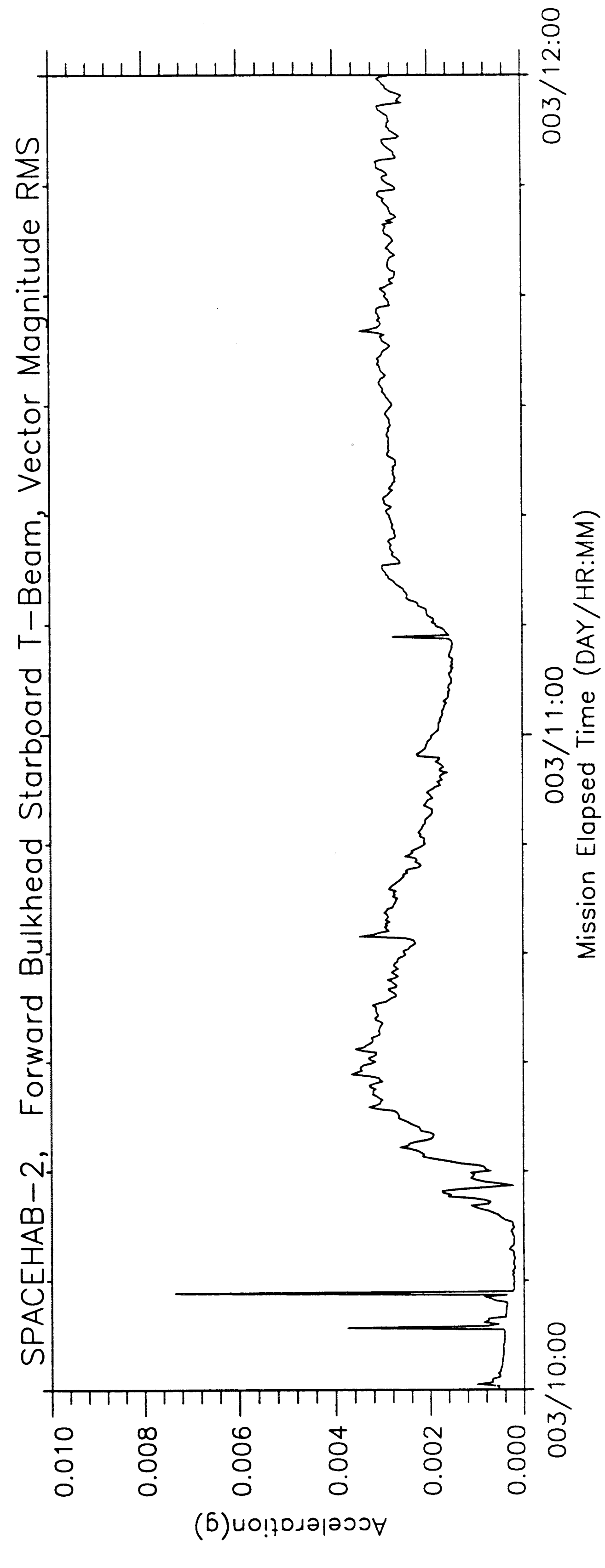
Mission Elapsed Time (DAY/HR:MM)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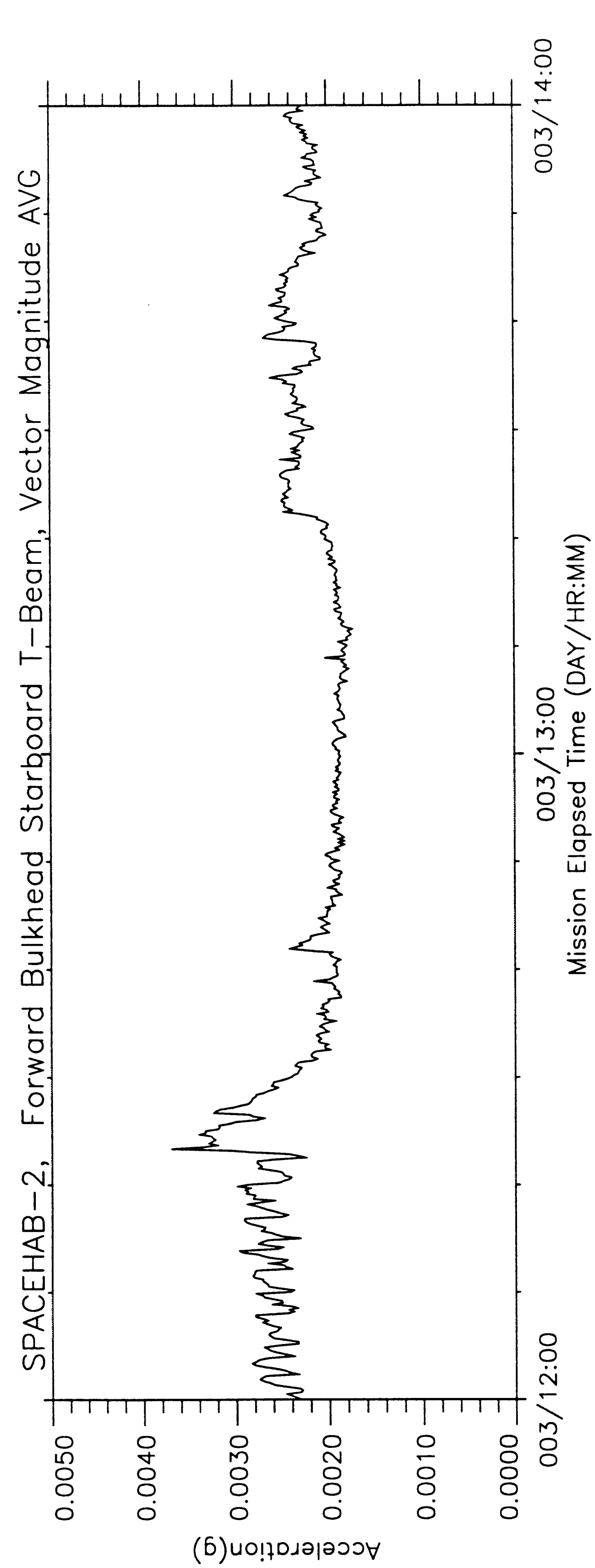
Mission Elapsed Time (DAY/HR:MM)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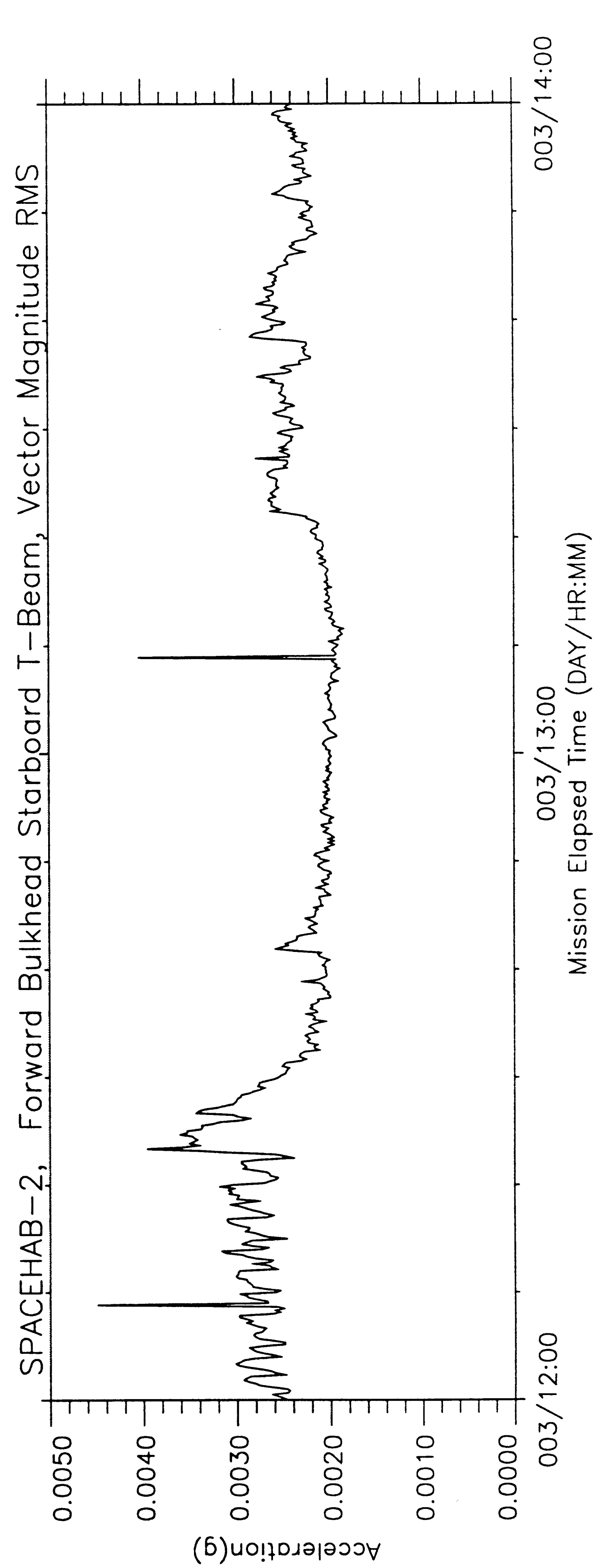
Mission Elapsed Time (DAY/HR:MM)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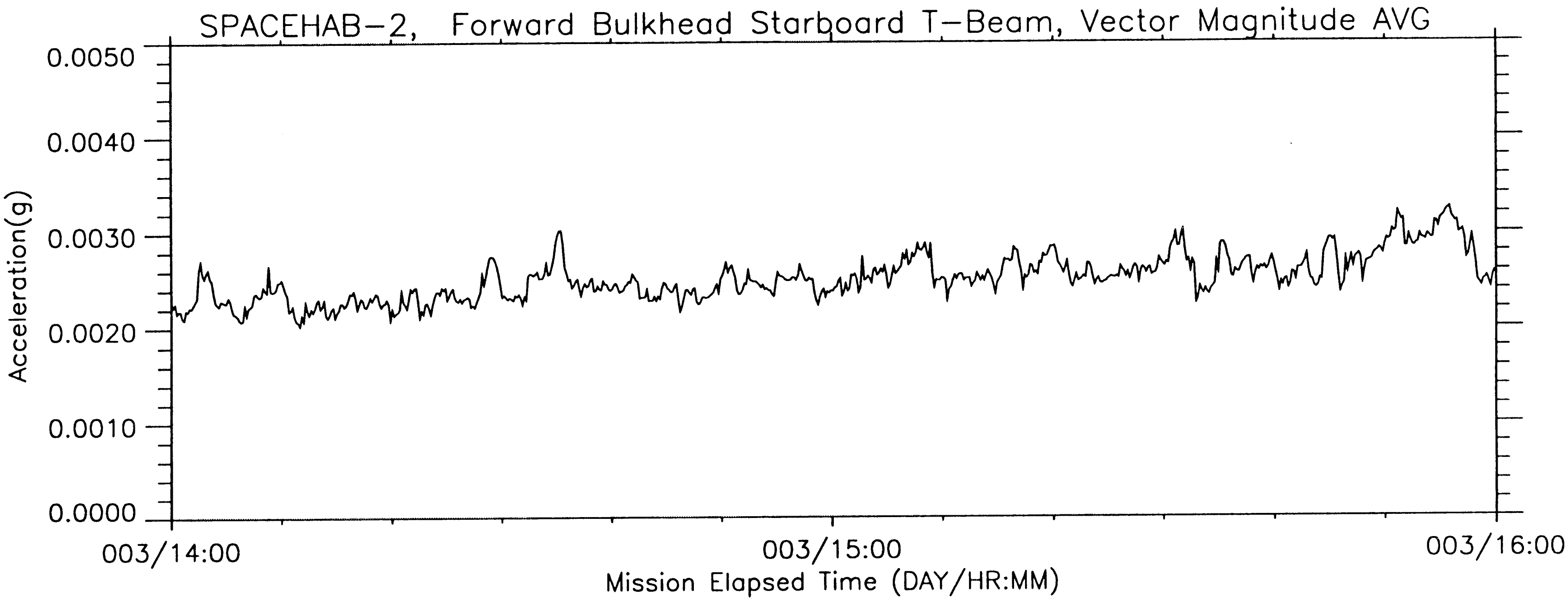
Mission Elapsed Time (DAY/HR:MM)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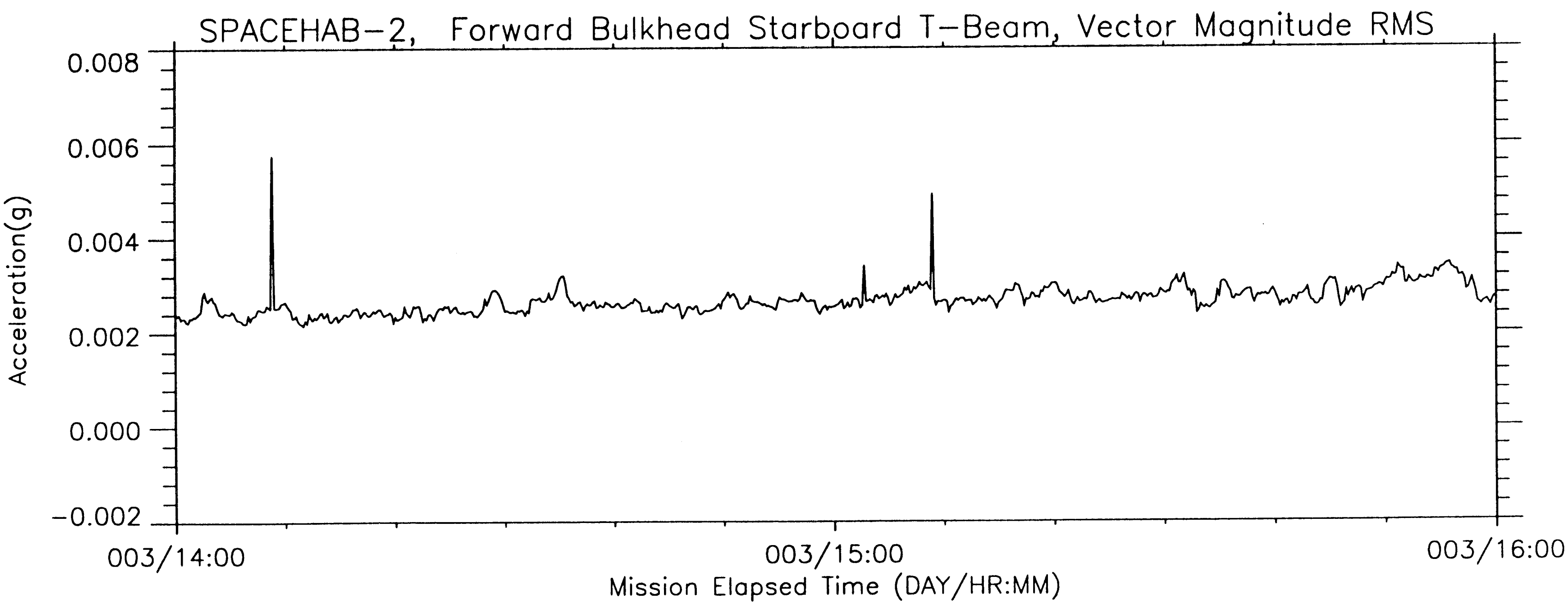
Mission Elapsed Time (DAY/HR:MM)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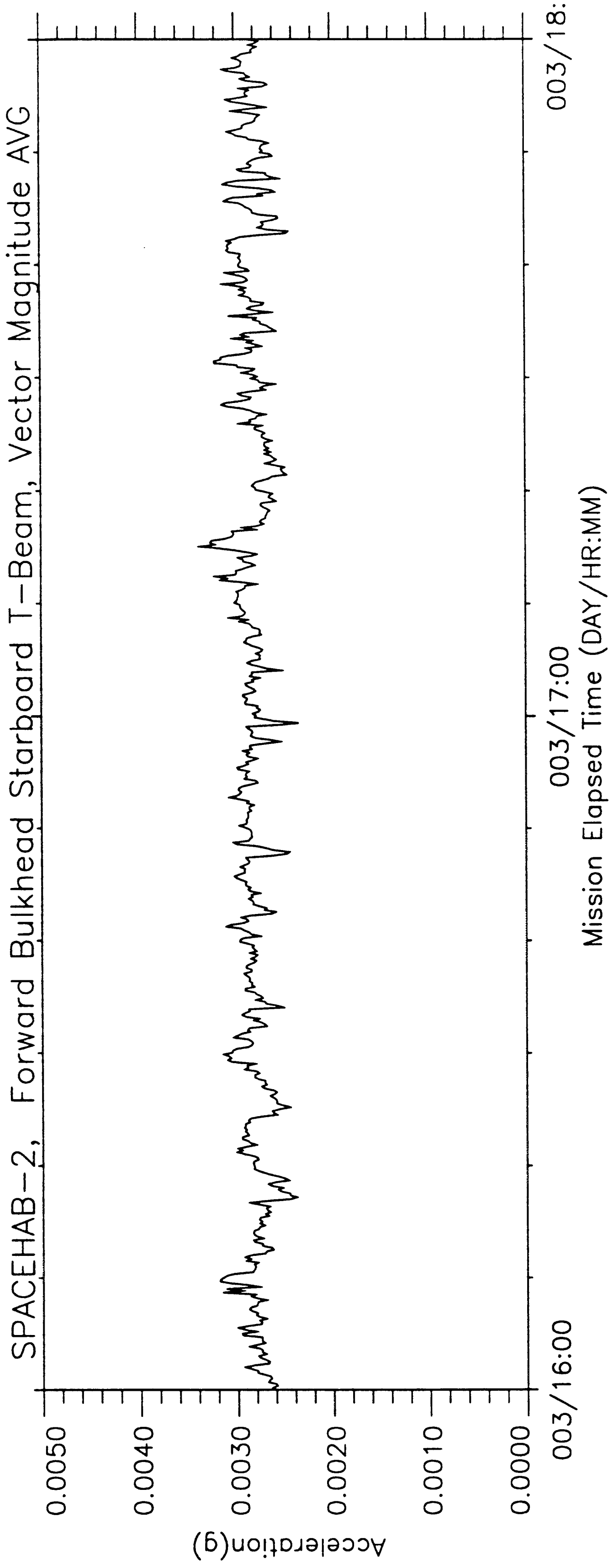
Mission Elapsed Time (DAY/HR:MM)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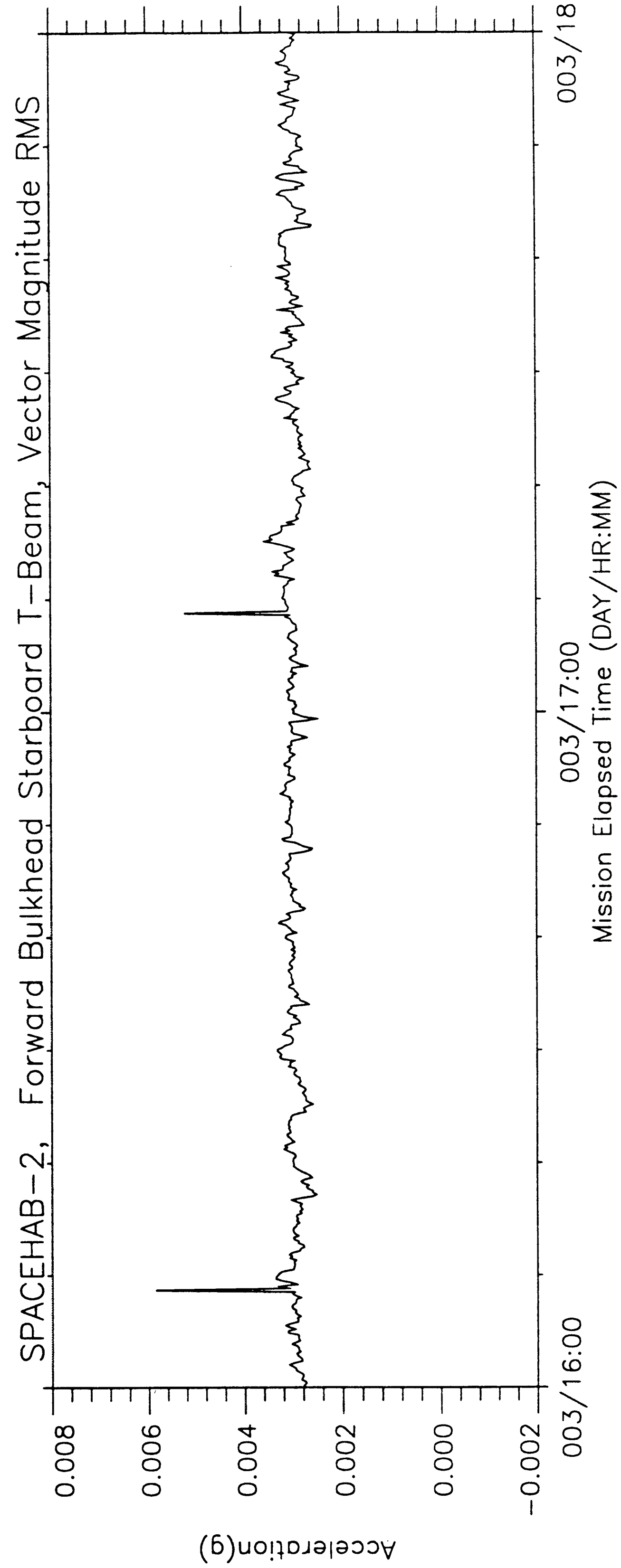
Mission Elapsed Time (DAY/HR:MM)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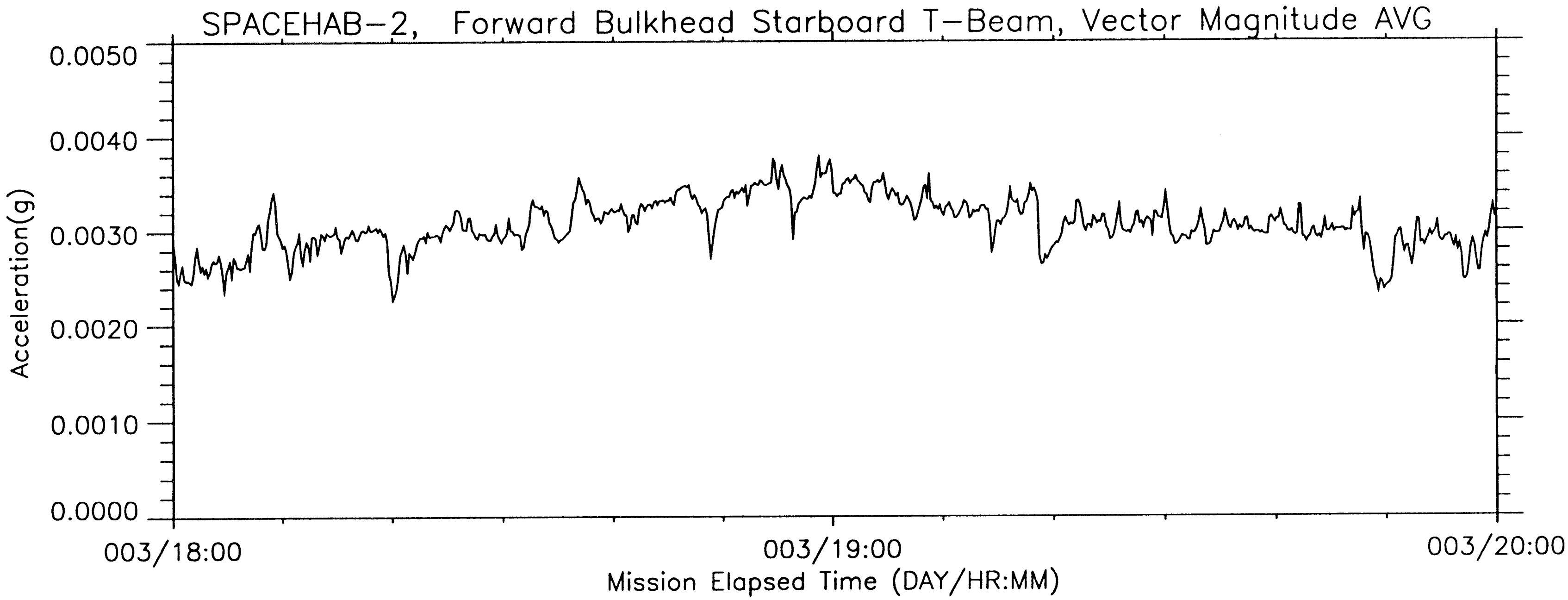
Mission Elapsed Time (DAY/HR:MM)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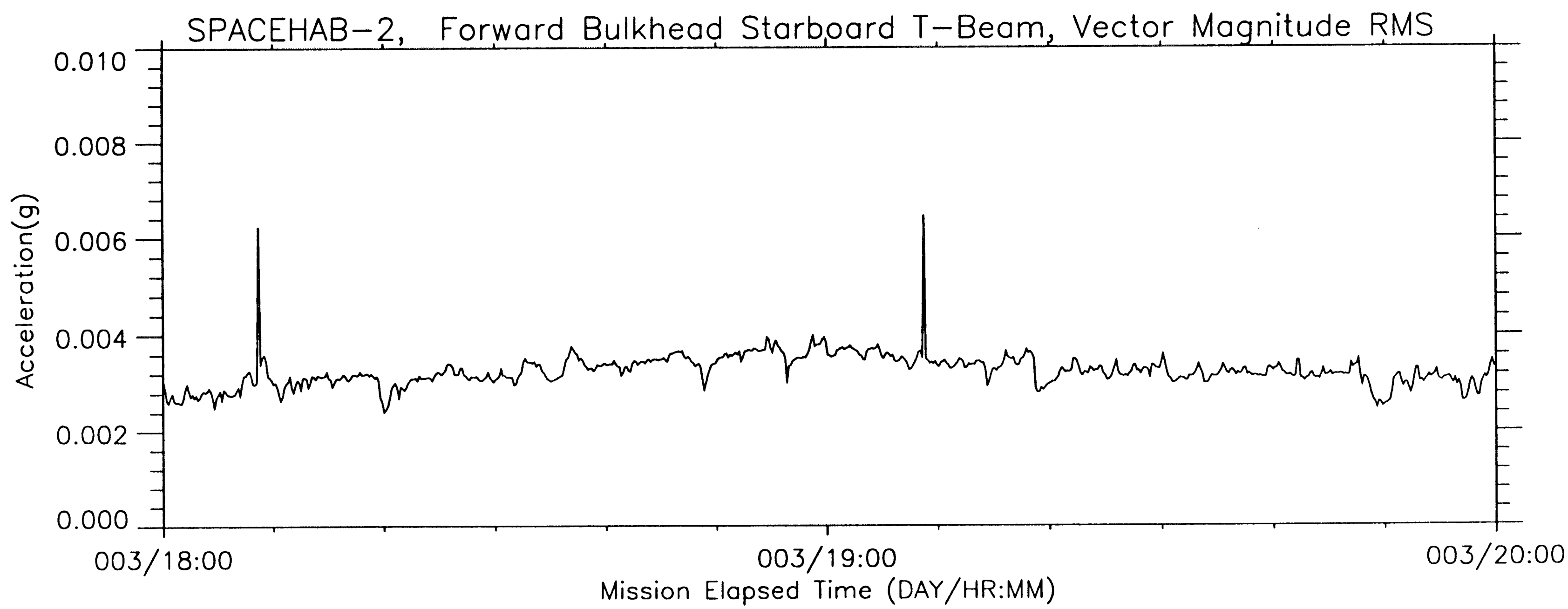
Mission Elapsed Time (DAY/HR:MM)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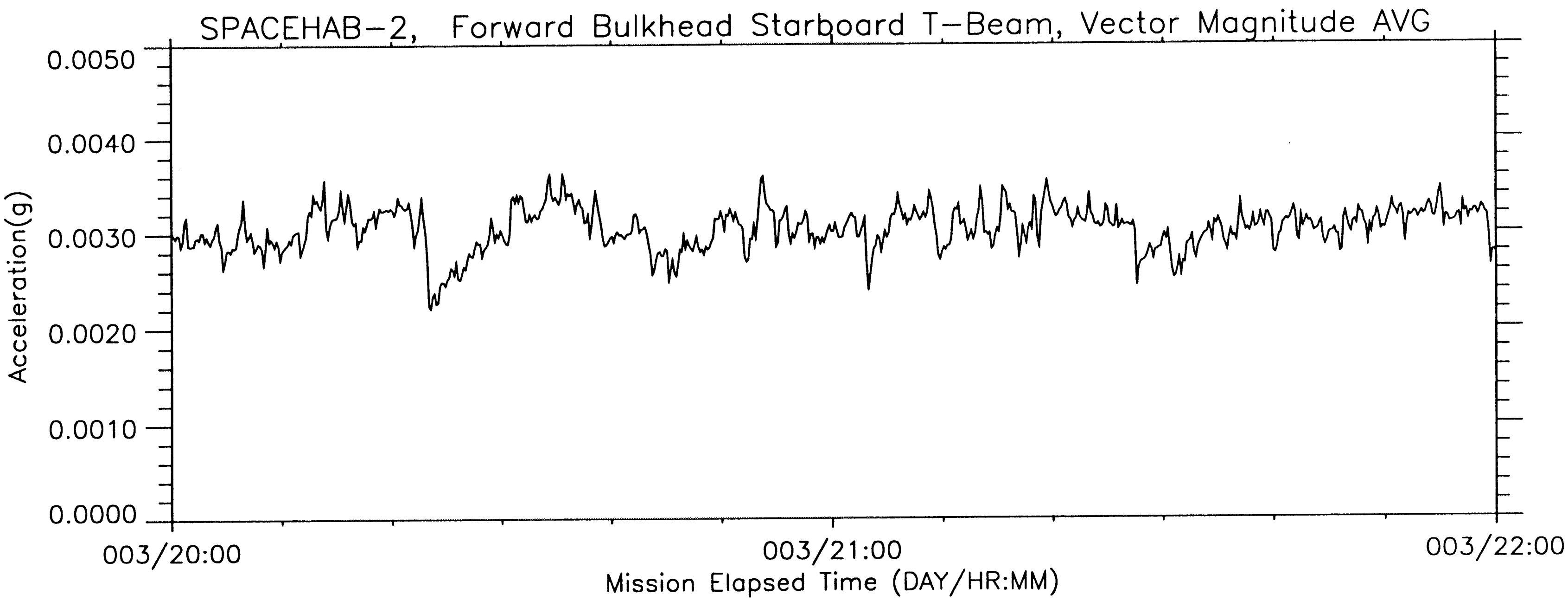
Mission Elapsed Time (DAY/HR:MM)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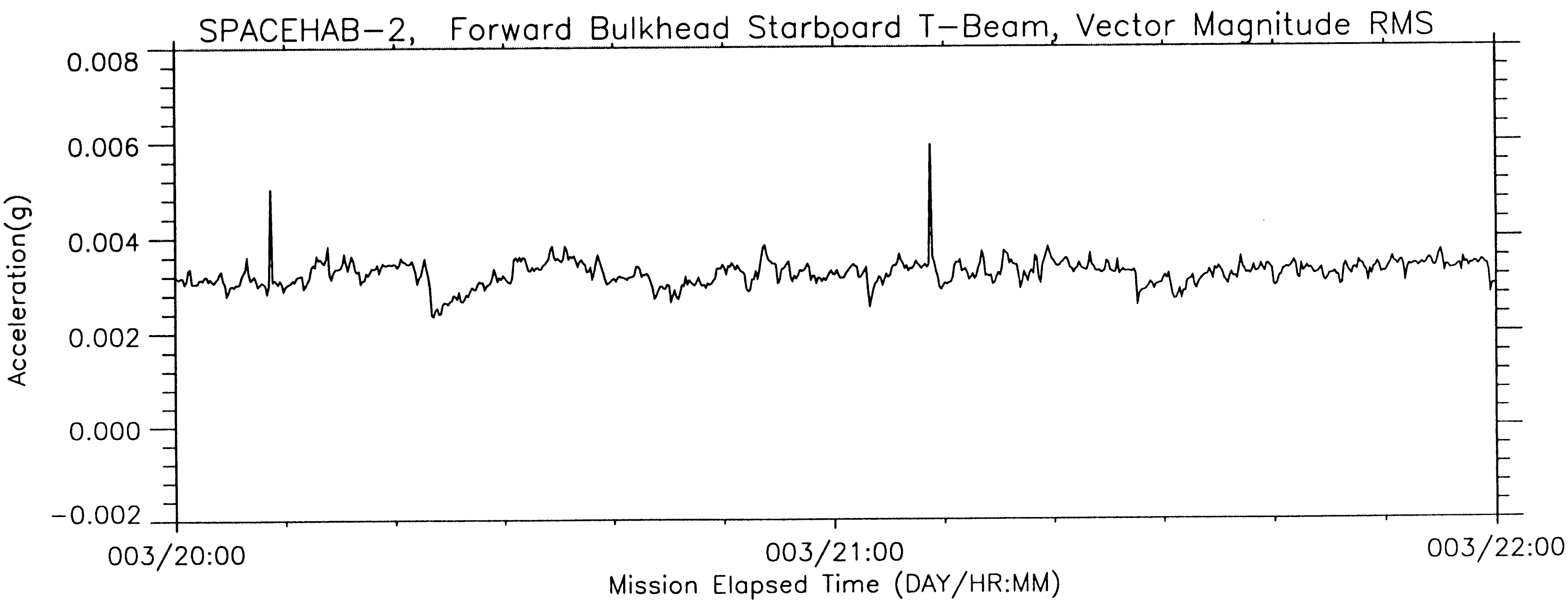
Mission Elapsed Time (DAY/HR:MM)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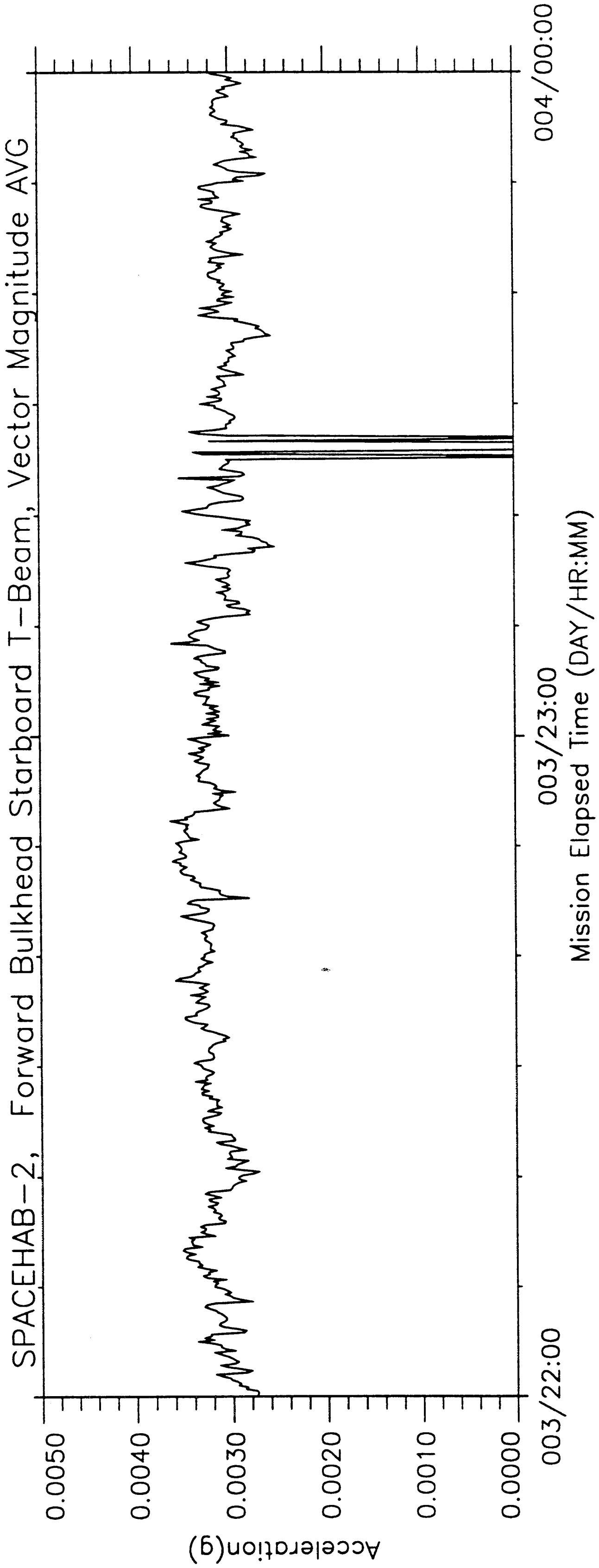
Mission Elapsed Time (DAY/HR:MM)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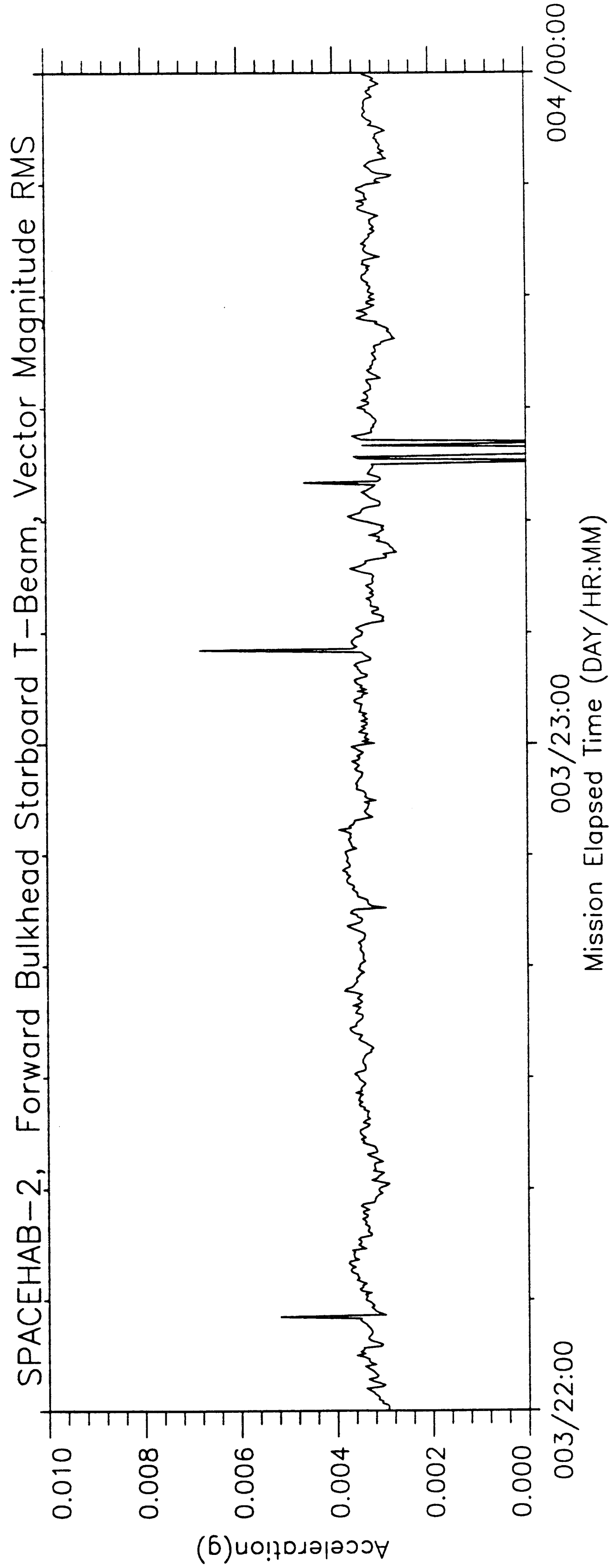
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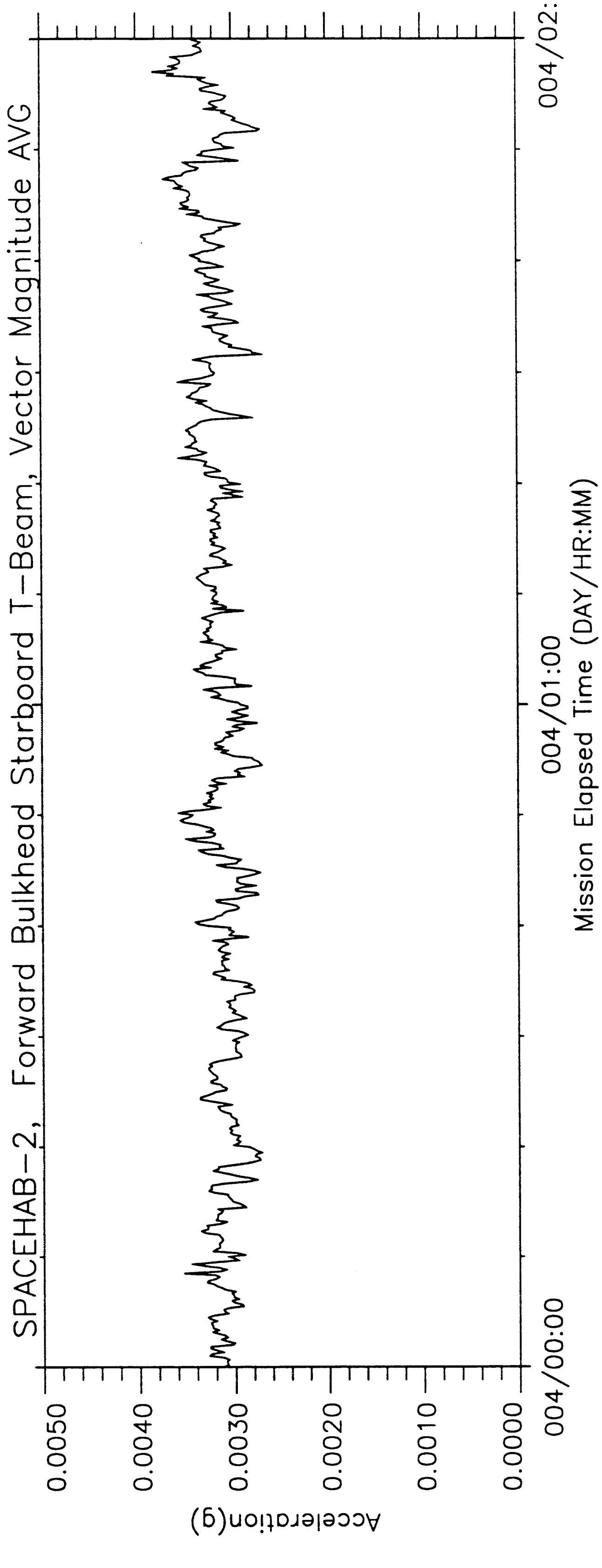
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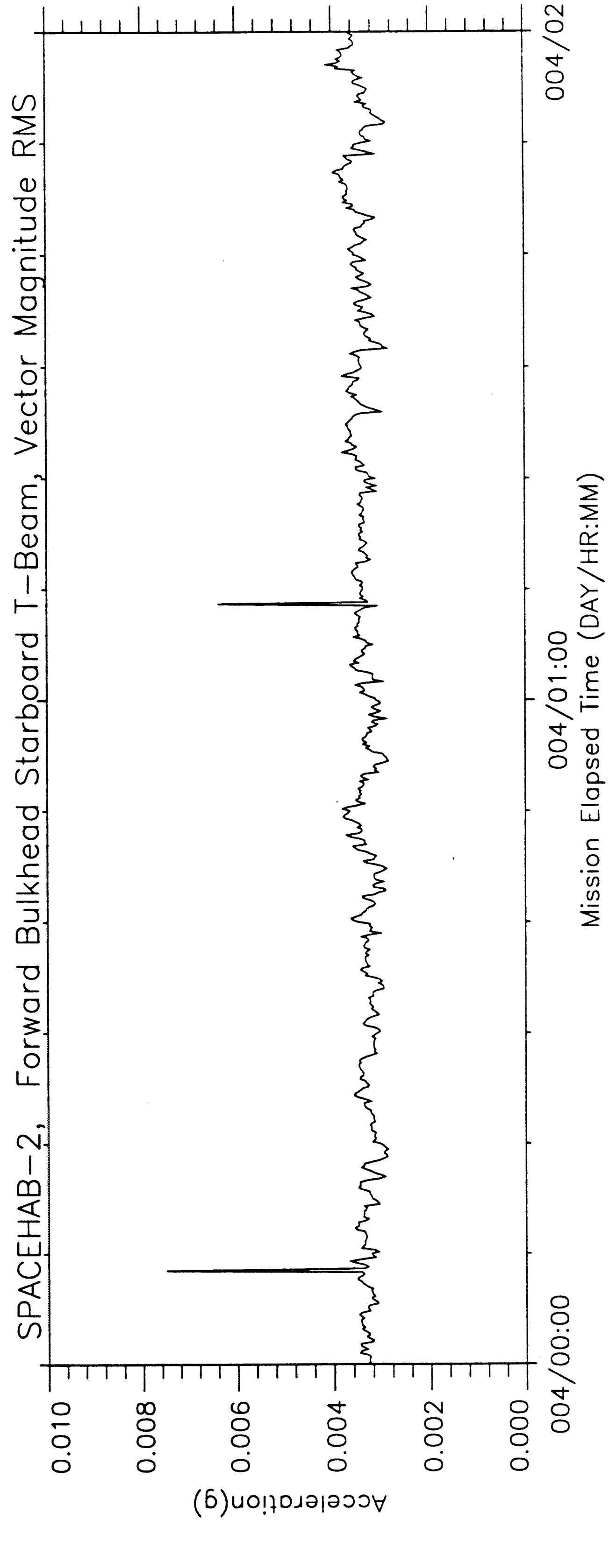
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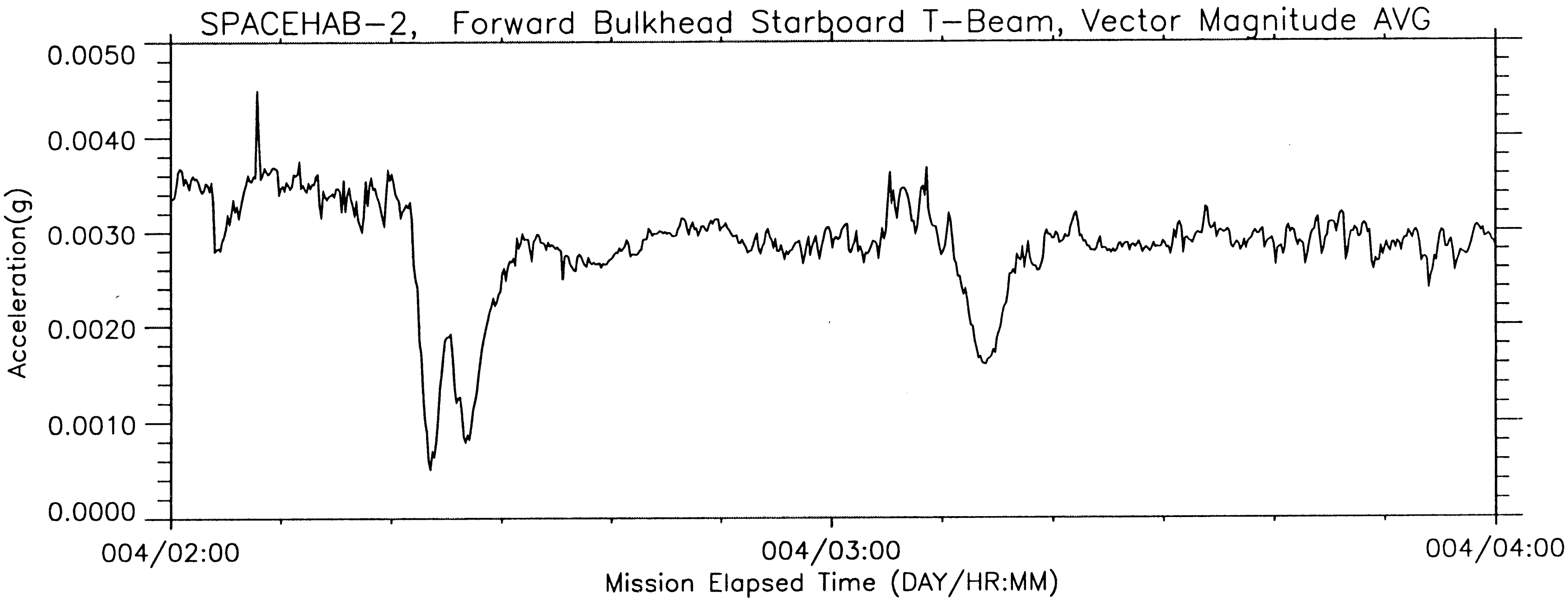
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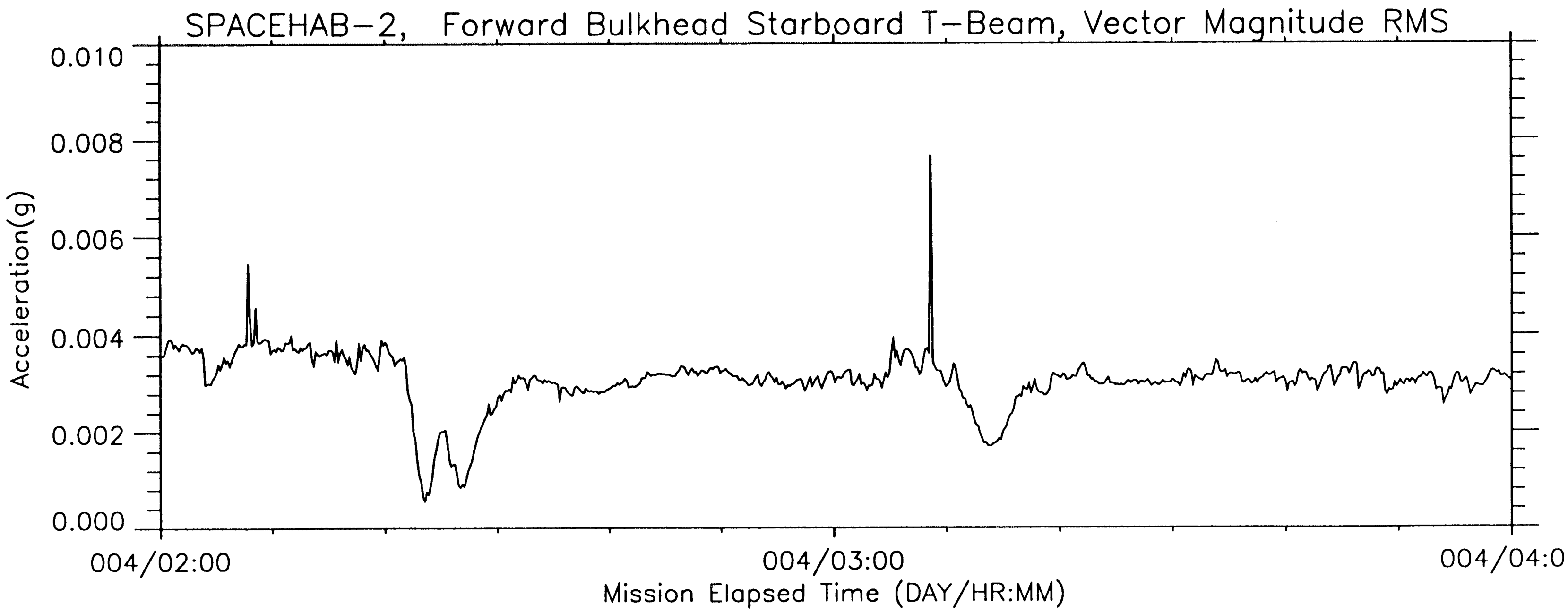
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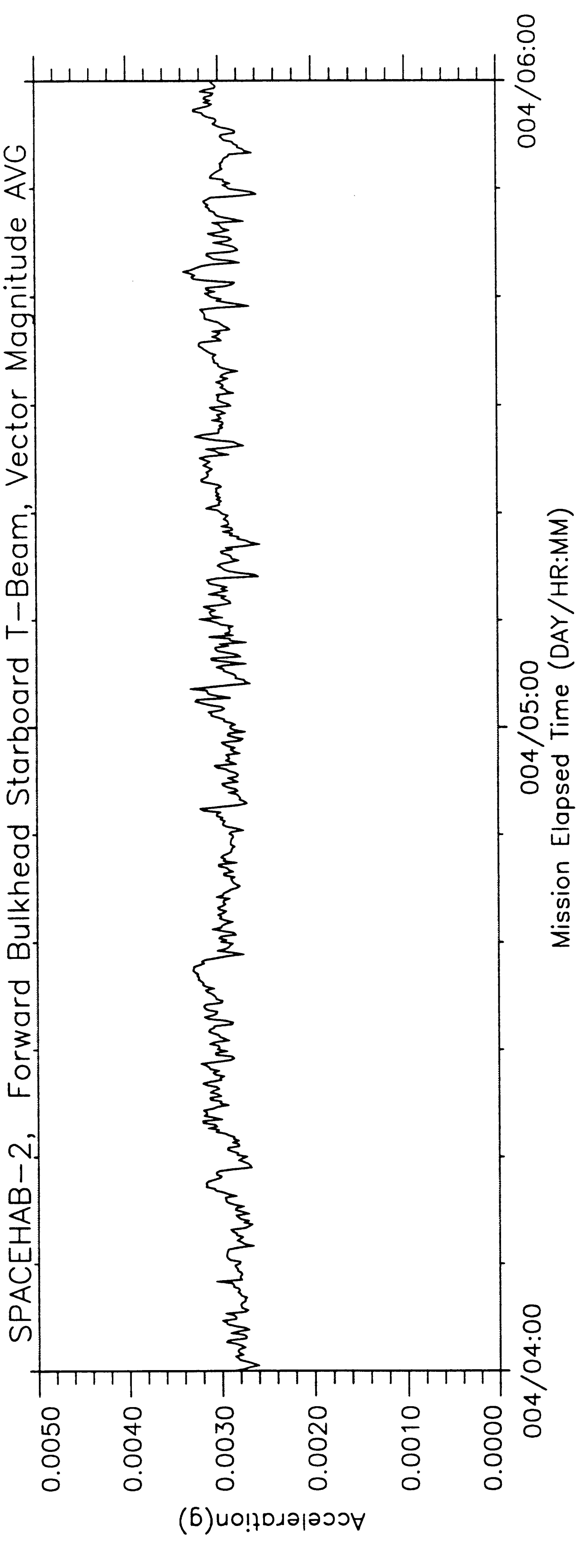
Mission Elapsed Time (DAY/HR:MM)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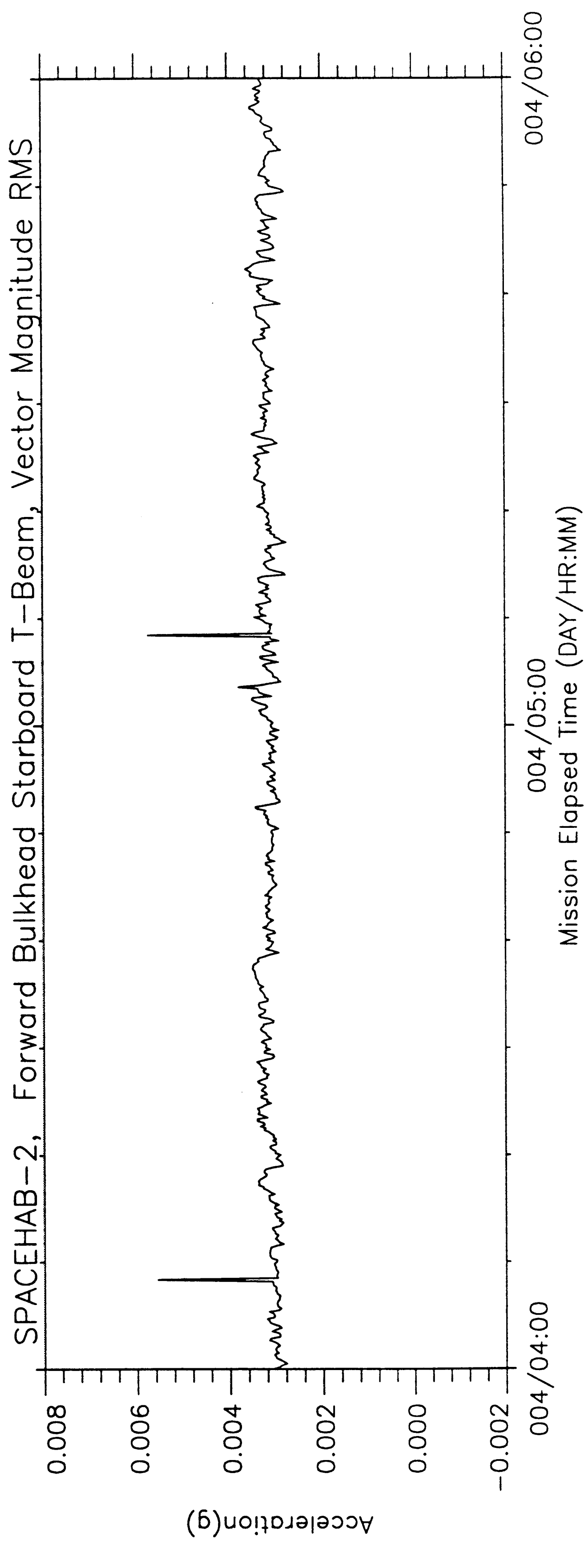
Mission Elapsed Time (DAY/HR:MM)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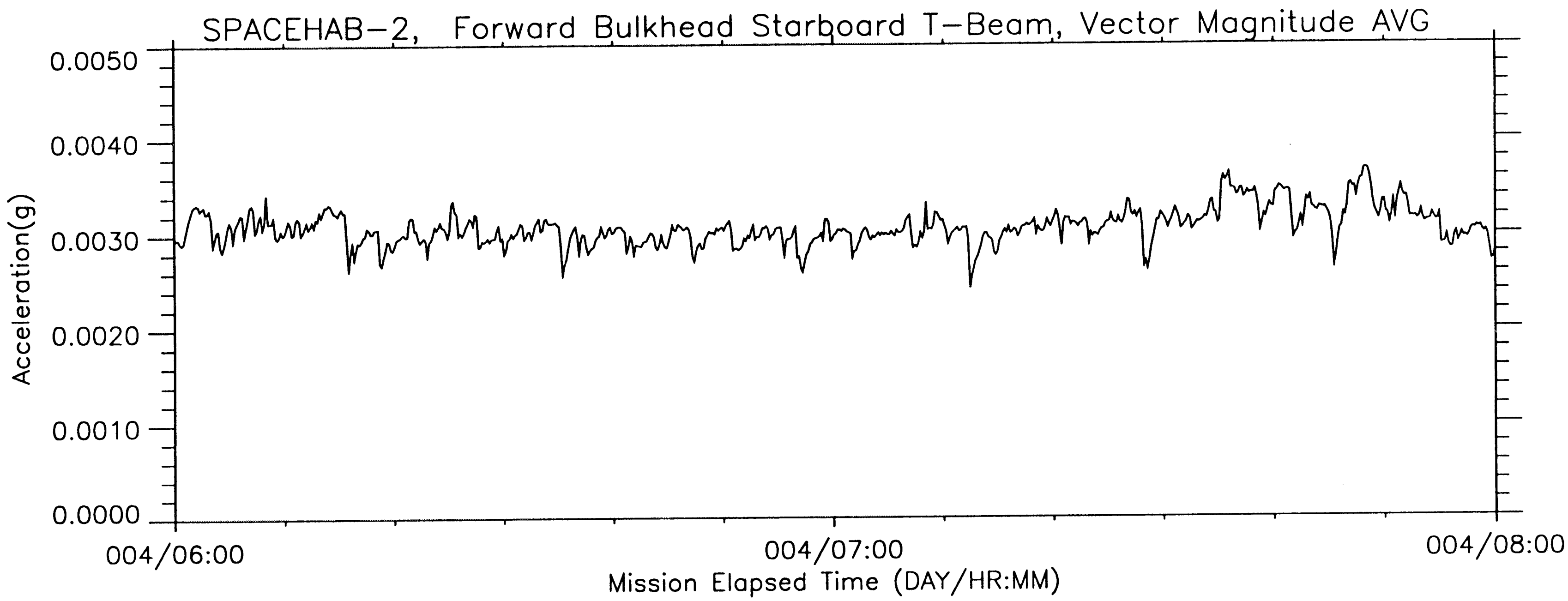
Mission Elapsed Time (DAY/HR:MM)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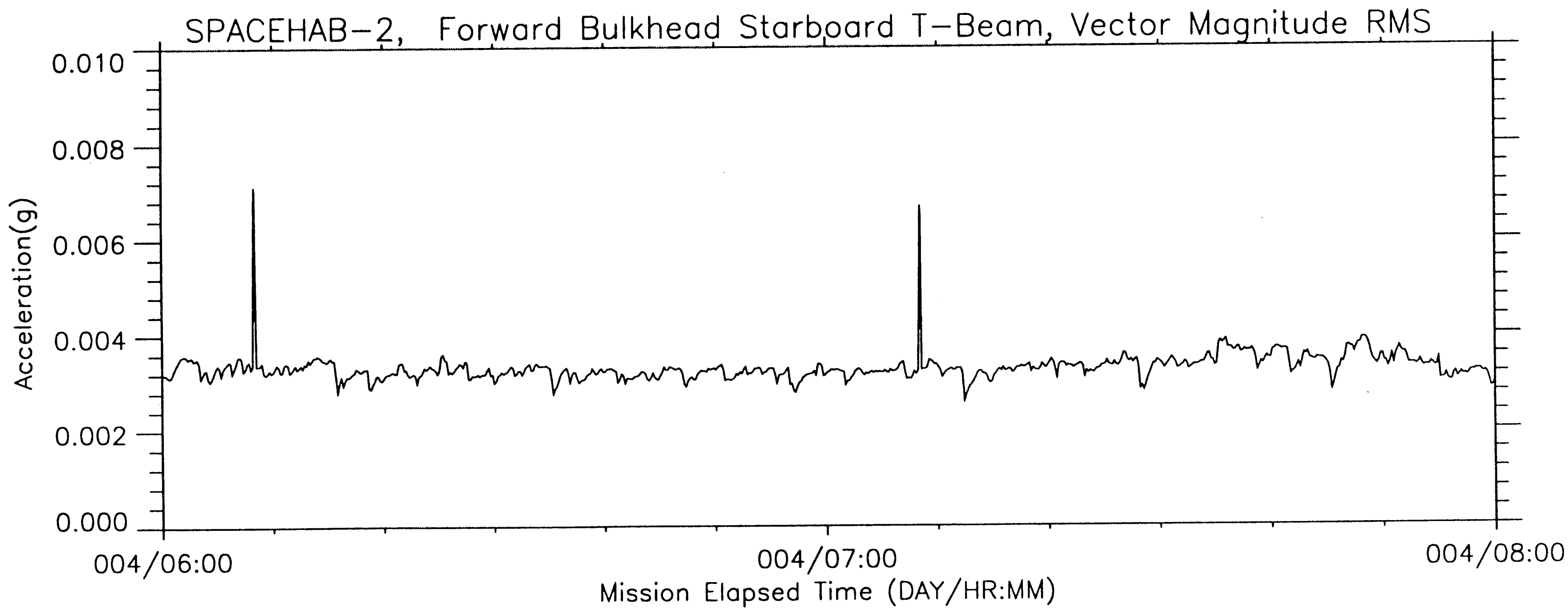
Mission Elapsed Time (DAY/HR:MM)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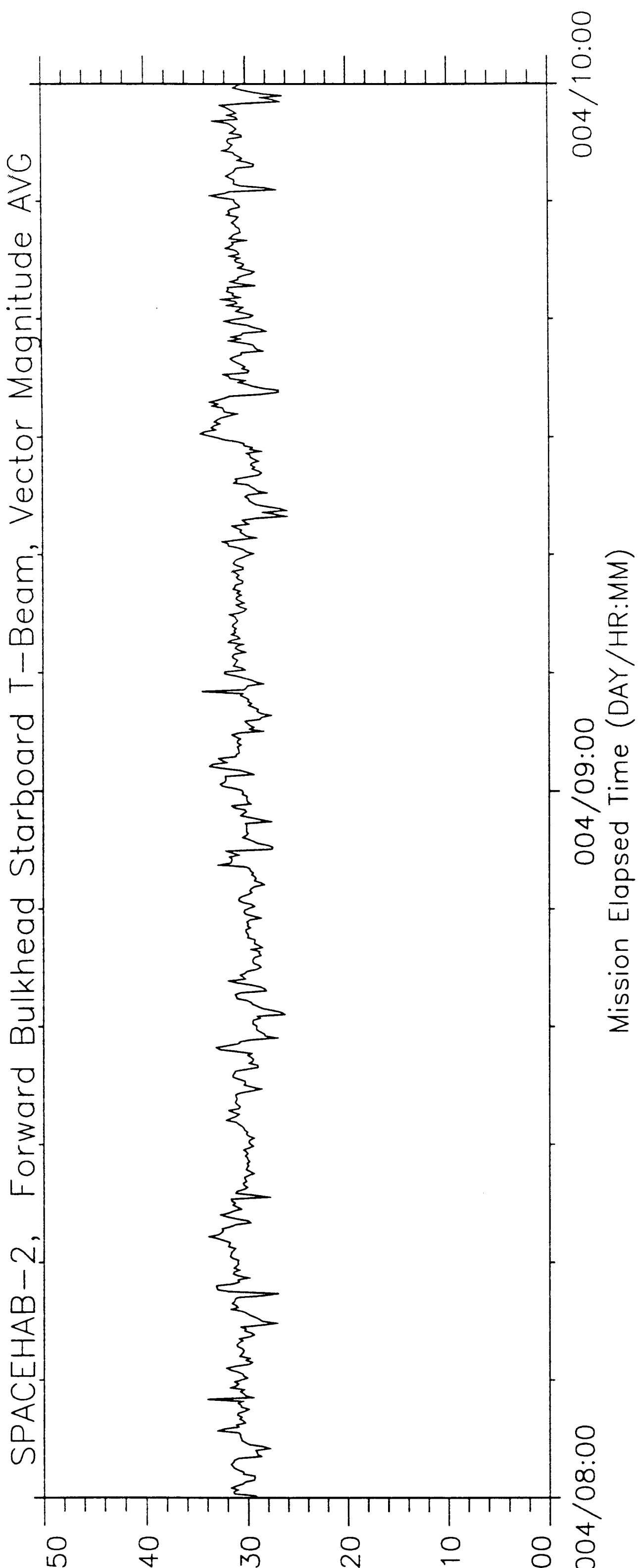
Mission Elapsed Time (DAY/HR:MM)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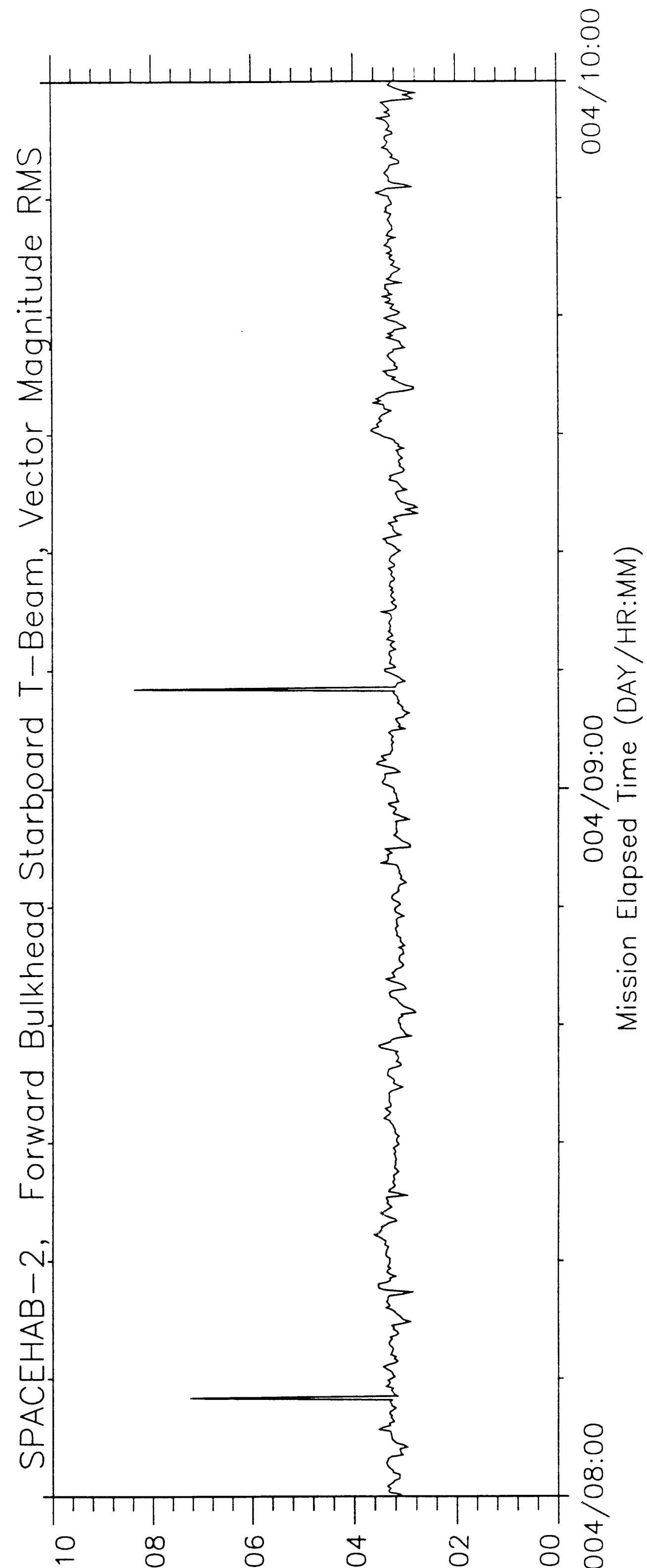
Mission Elapsed Time (DAY/HR:MM)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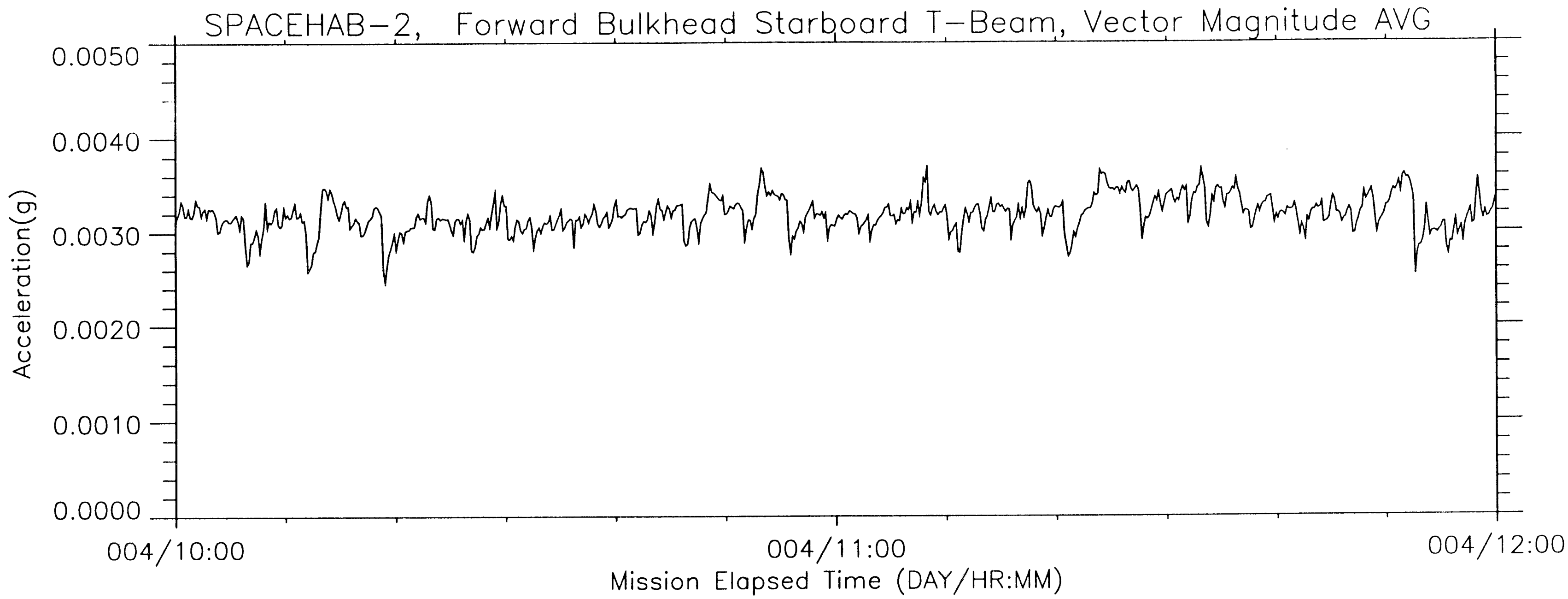
Mission Elapsed Time (DAY/HR:MM)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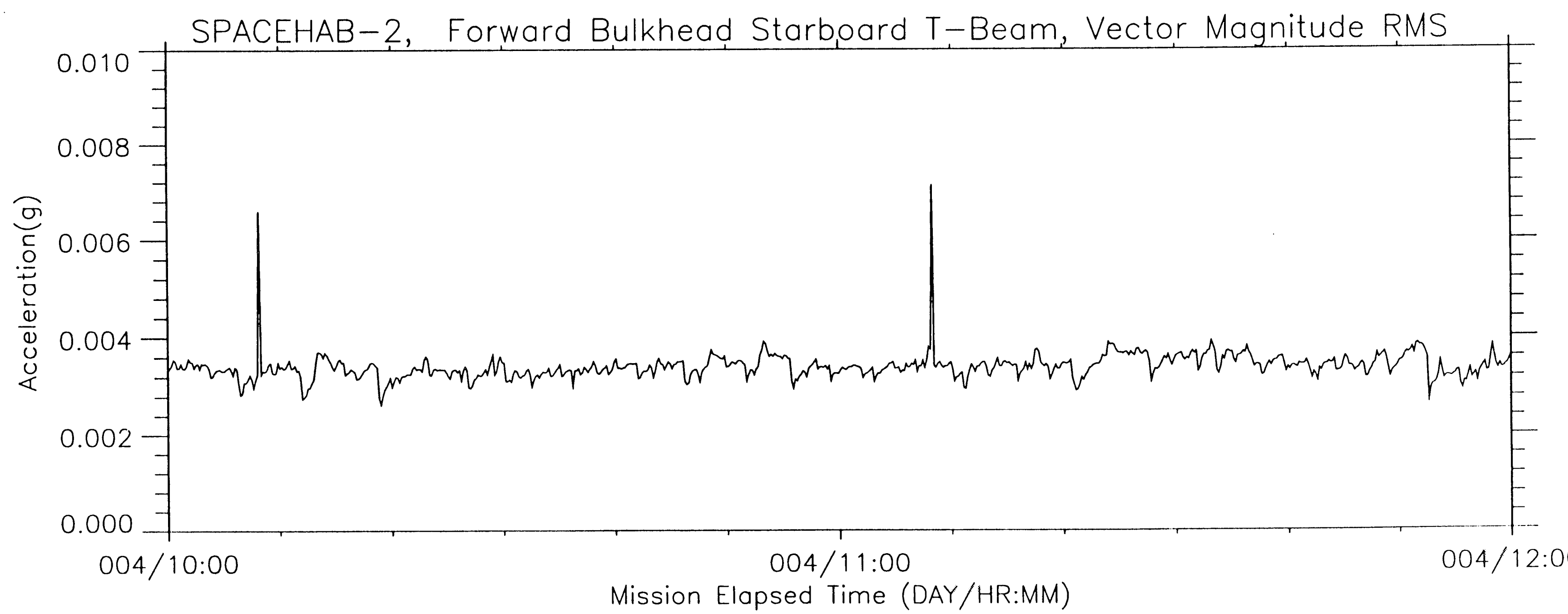
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Acceleration(g)
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Mission Elapsed Time (DAY/HR:MM)

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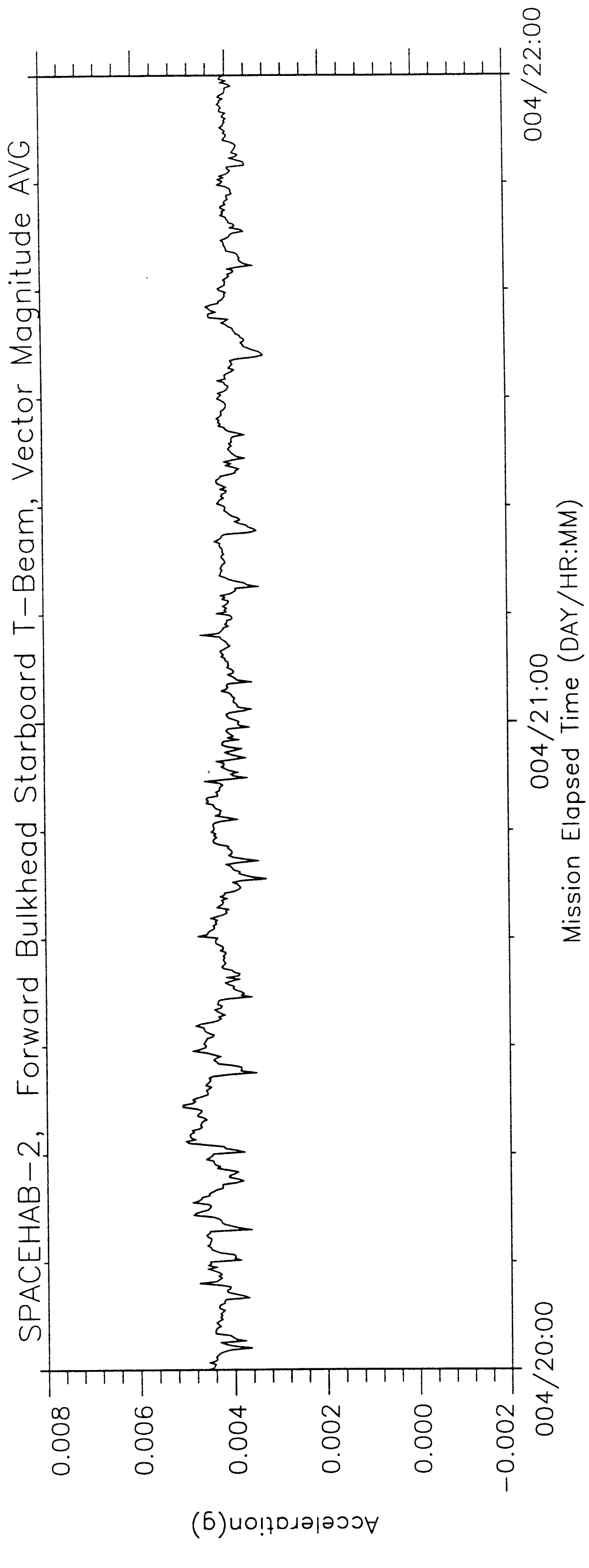
FROM MET 004/12:00:00 - 004/20:00:00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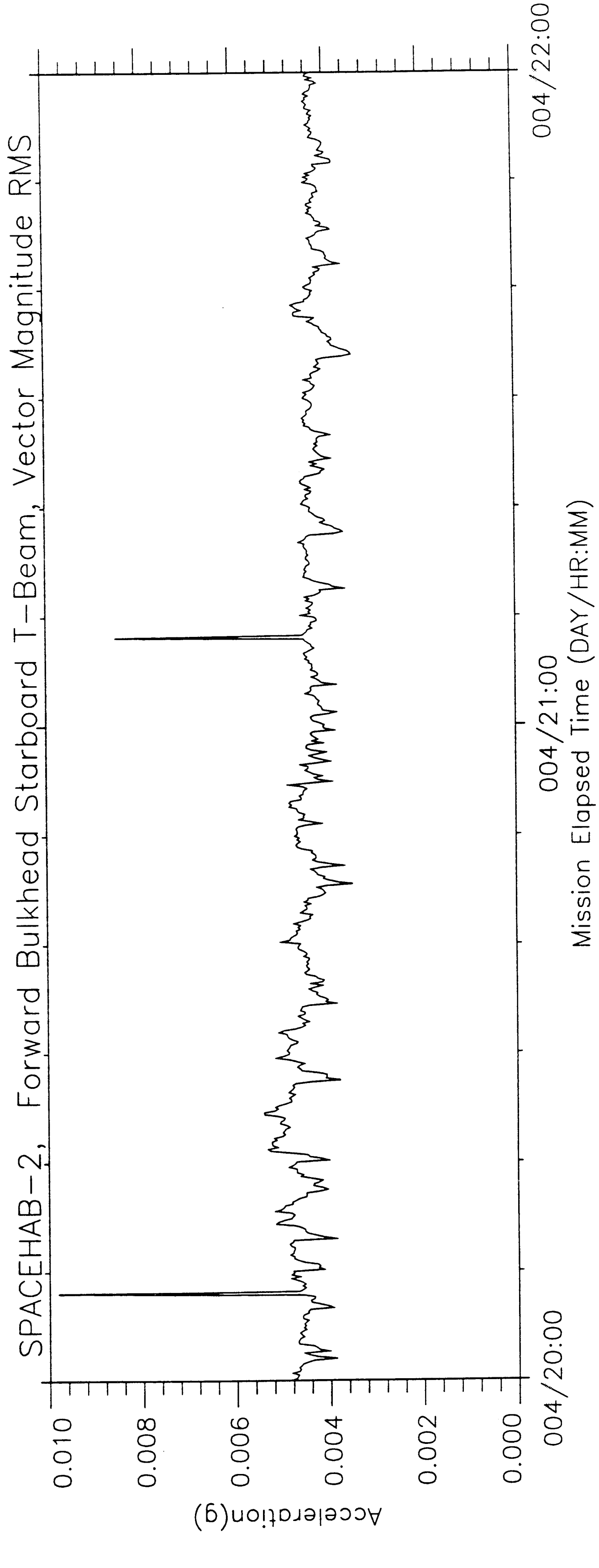
Mission Elapsed Time (DAY/HR:MM)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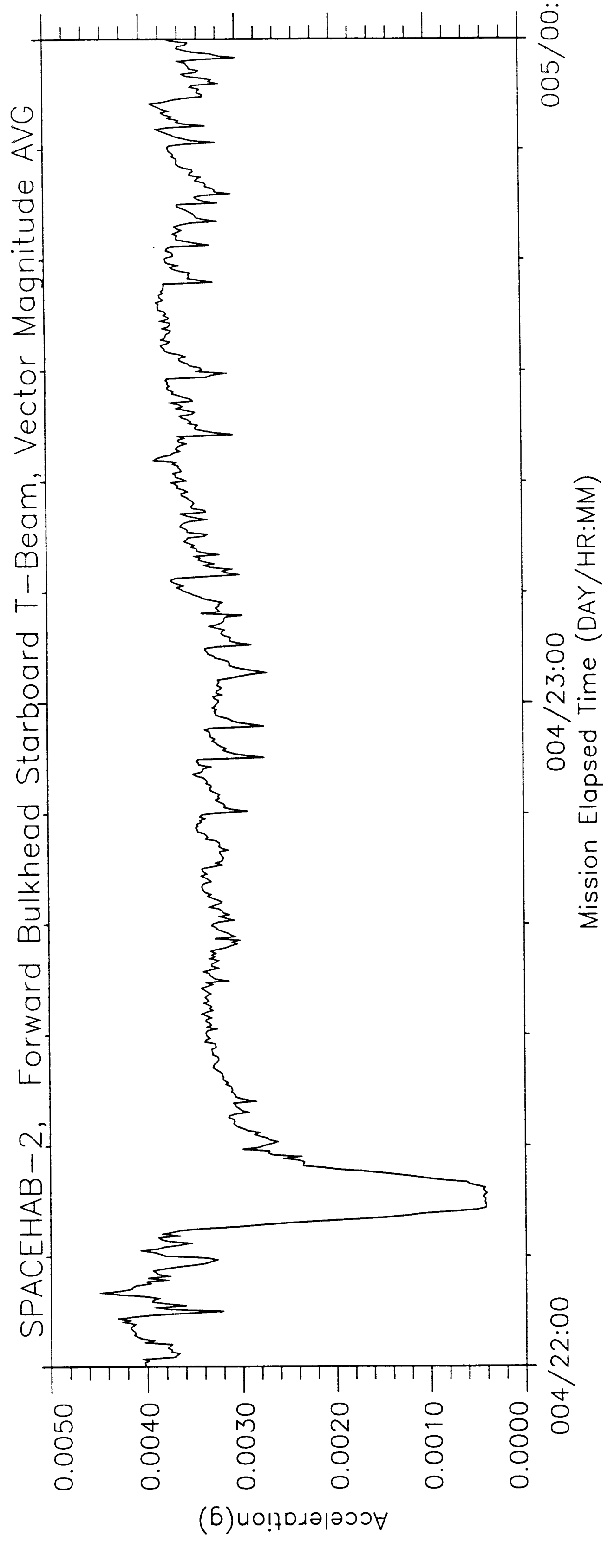
Mission Elapsed Time (DAY/HR:MM)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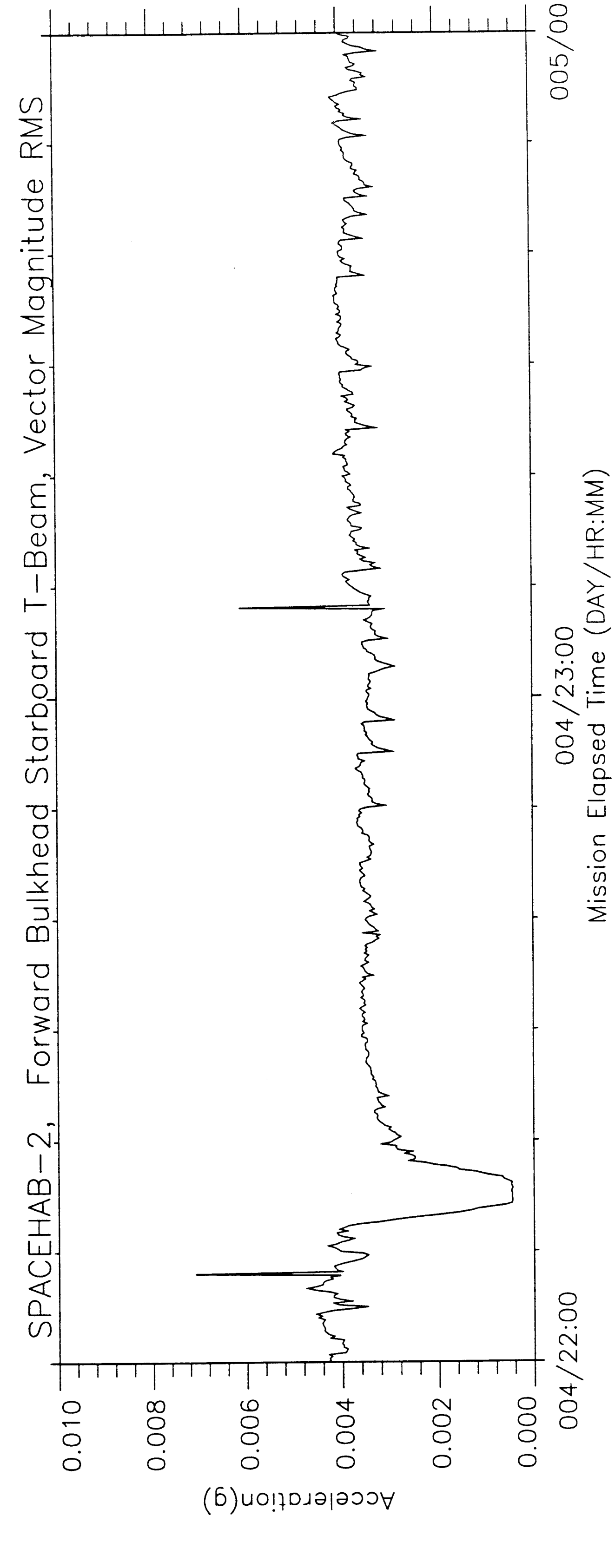
Mission Elapsed Time (DAY/HR:MM)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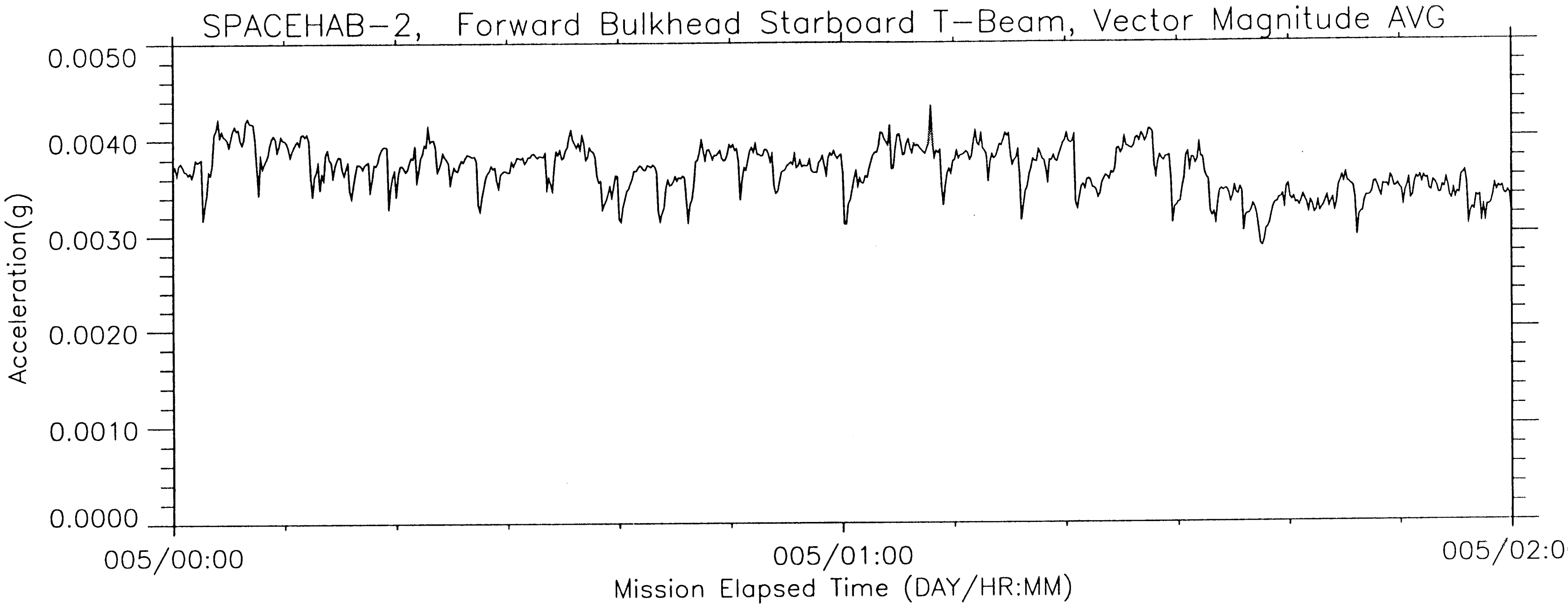
Mission Elapsed Time (DAY/HR:MM)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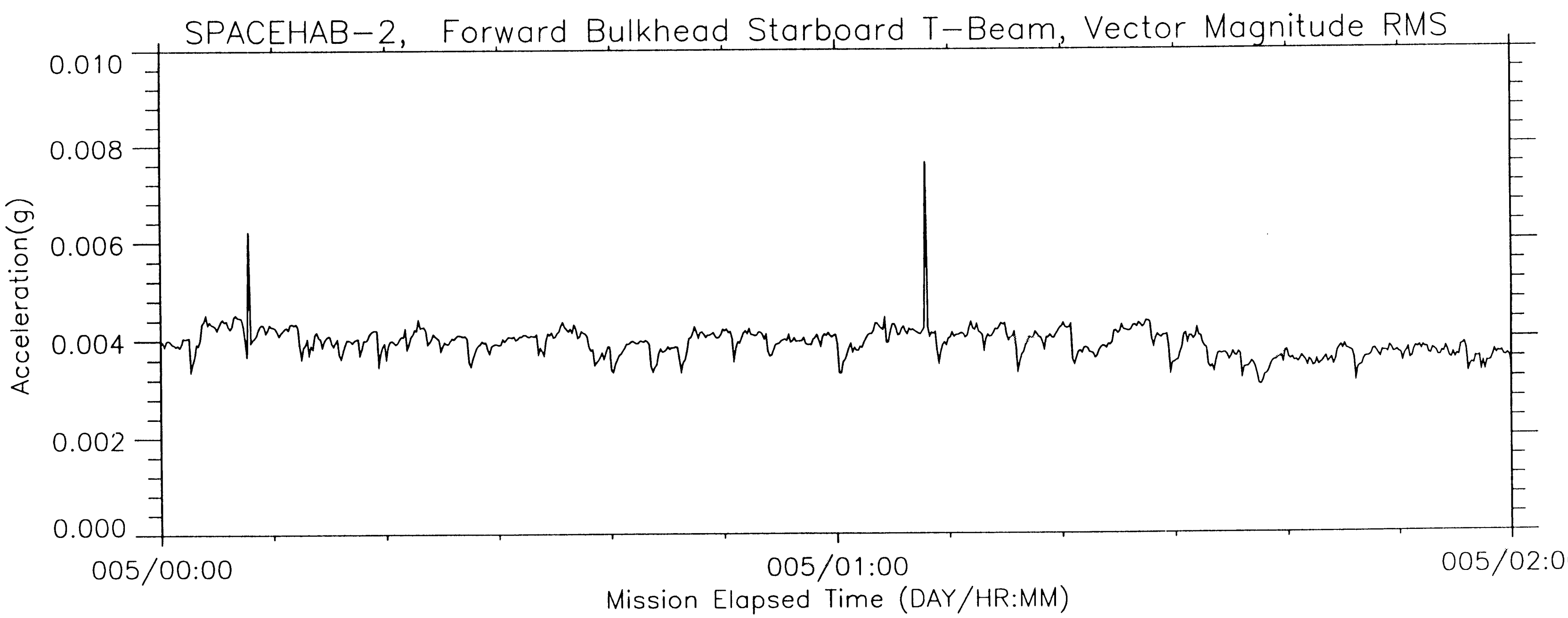
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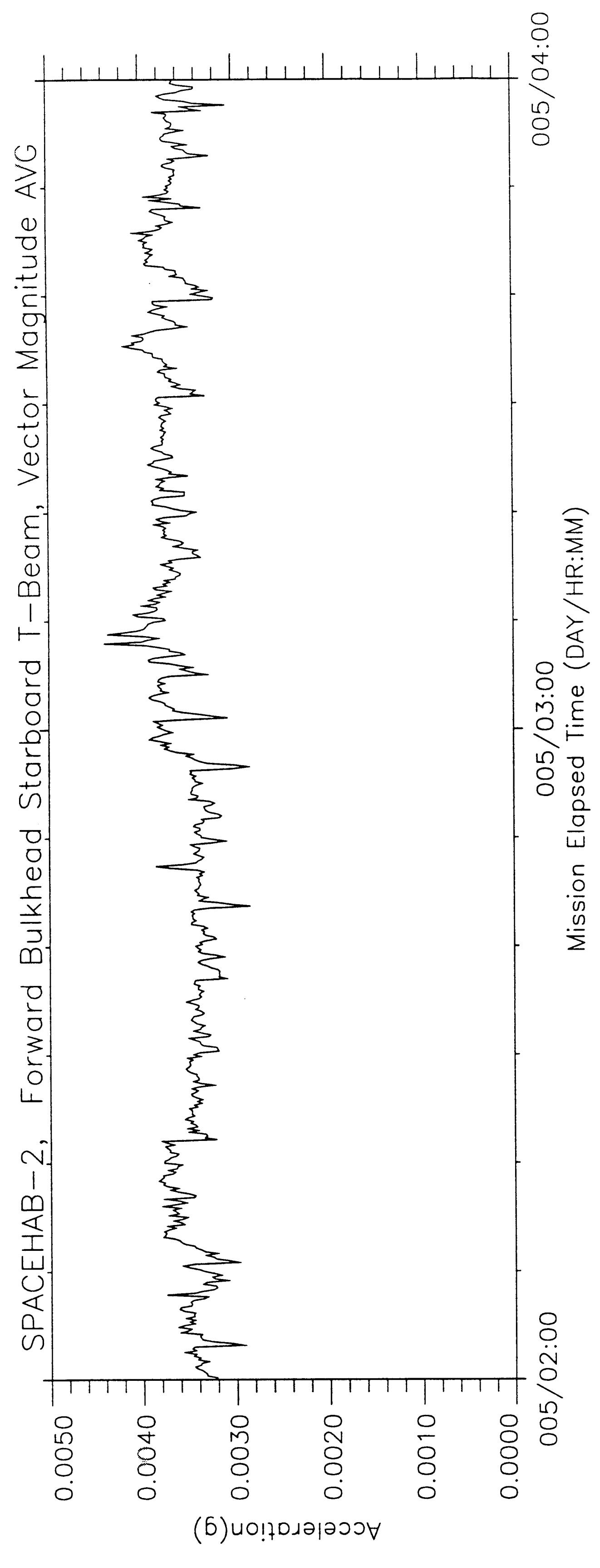
Mission Elapsed Time (DAY/HR:MM)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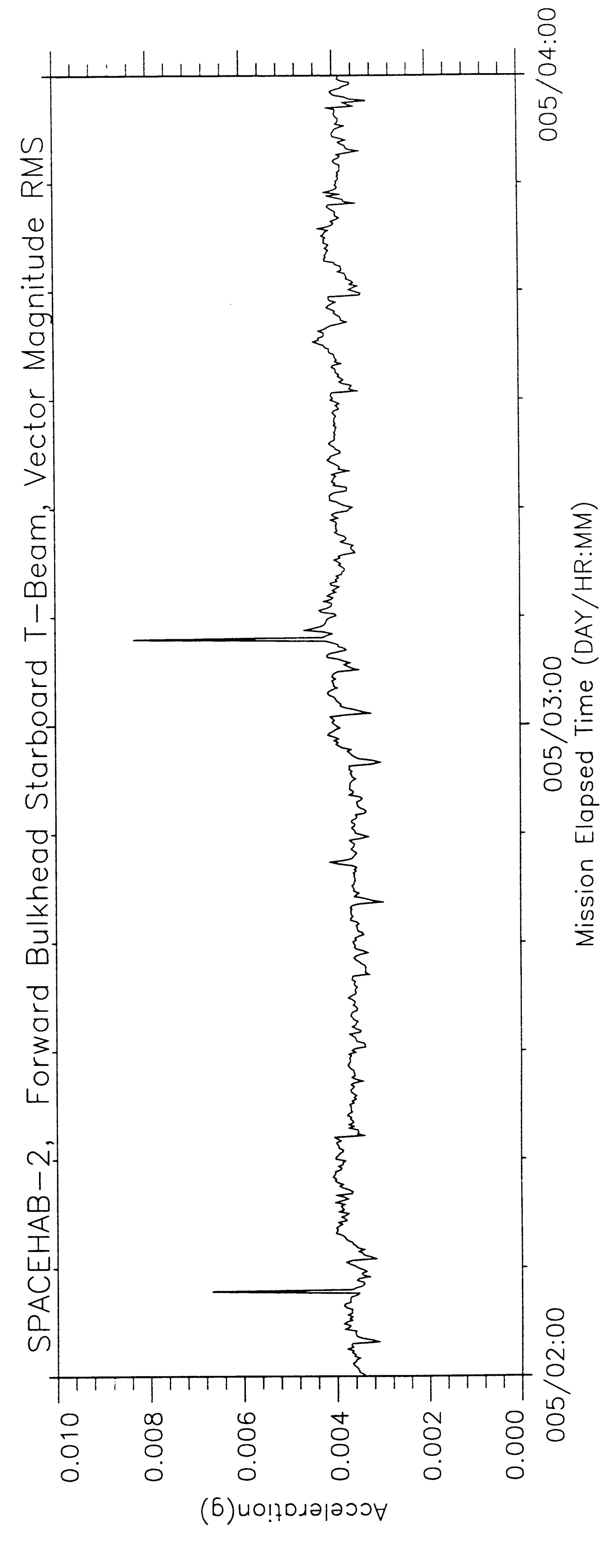
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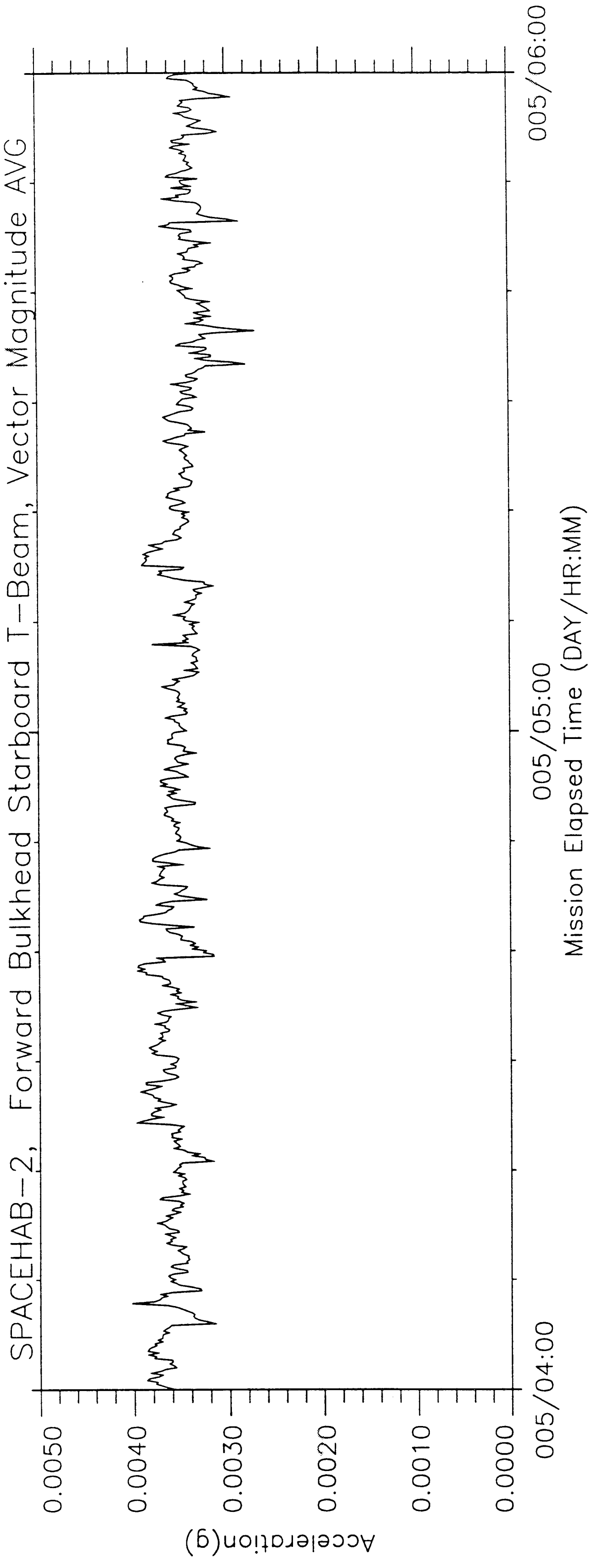
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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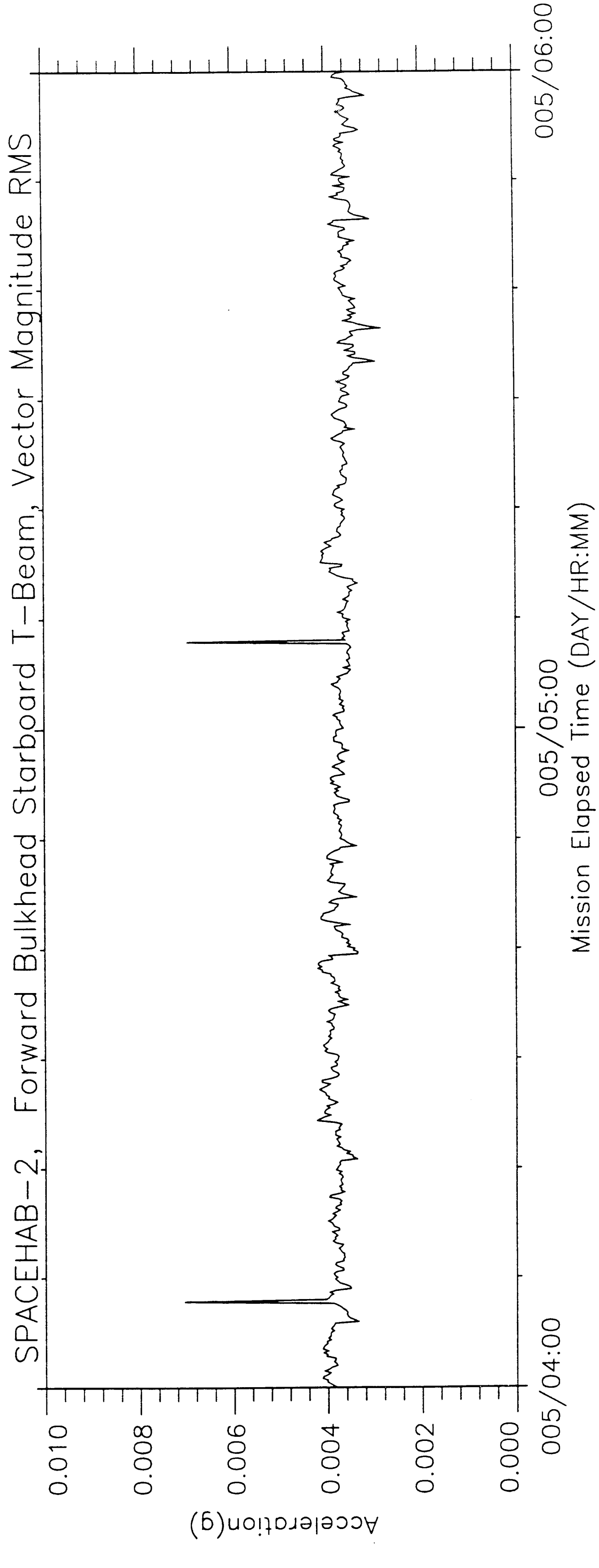
005/06:00
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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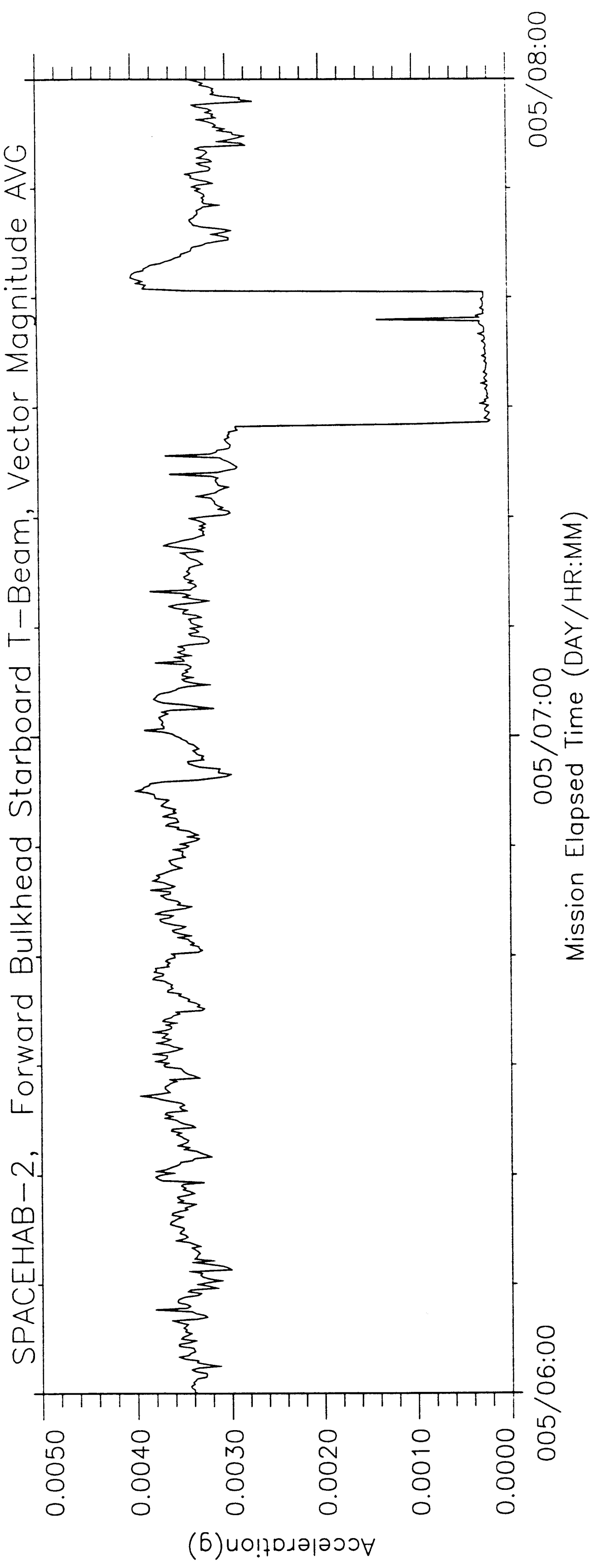
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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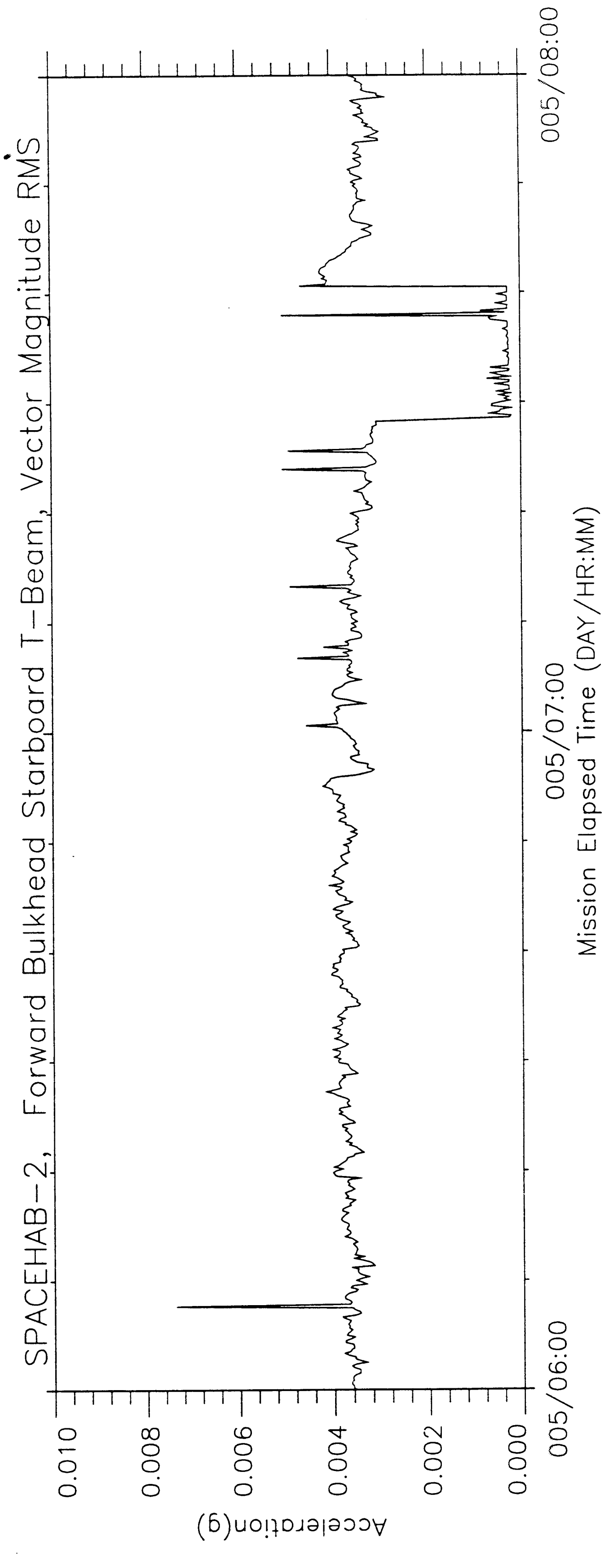
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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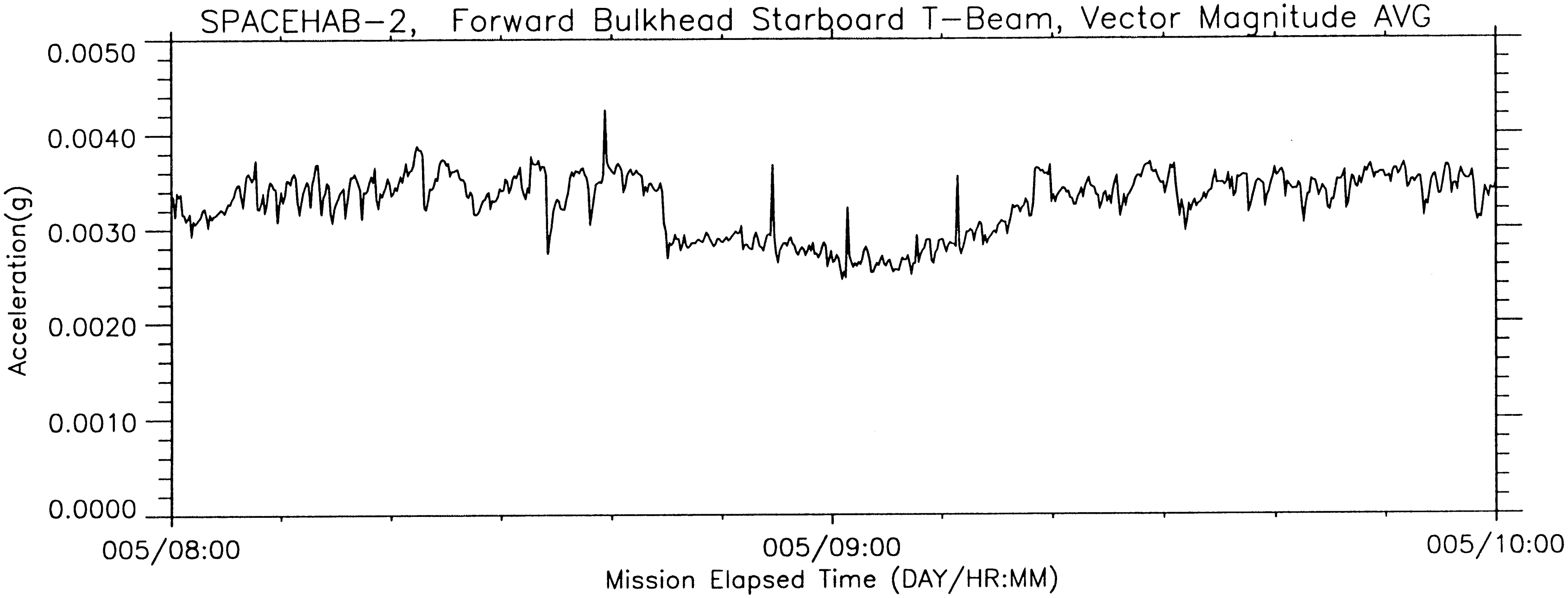
005/08:00
Mission Elapsed Time (DAY/HR:MM)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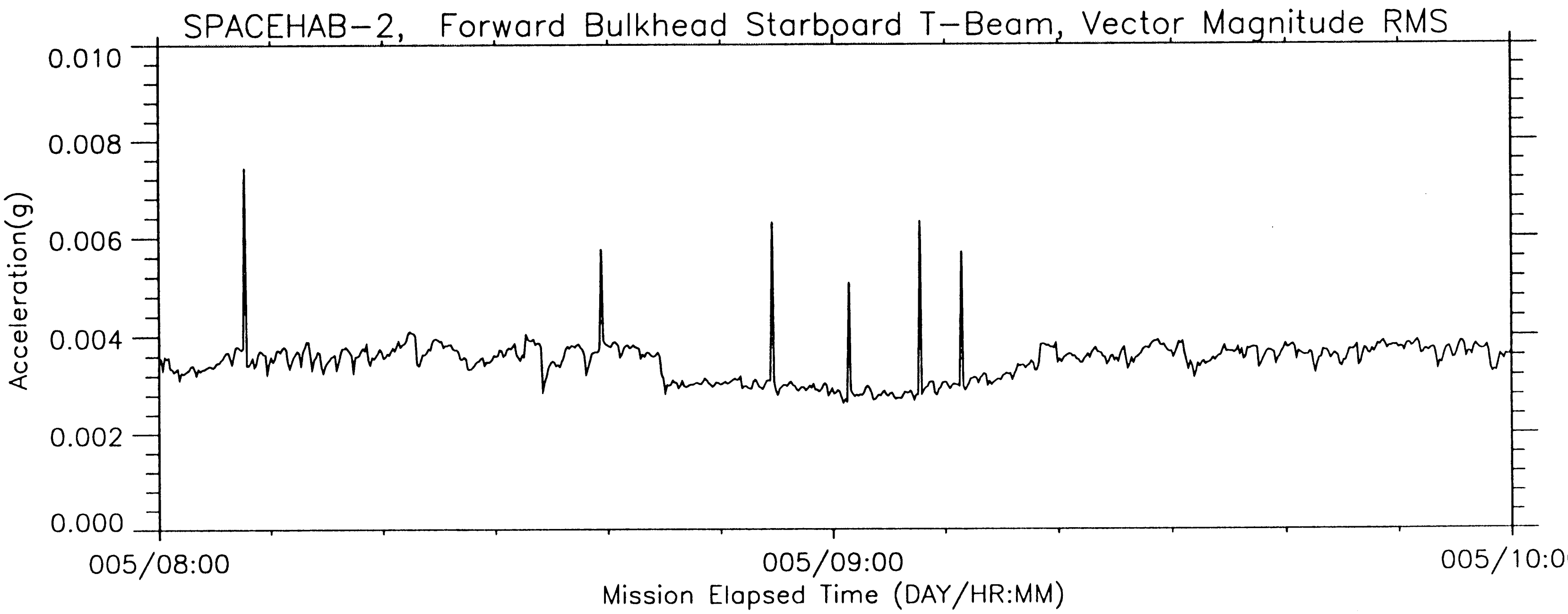
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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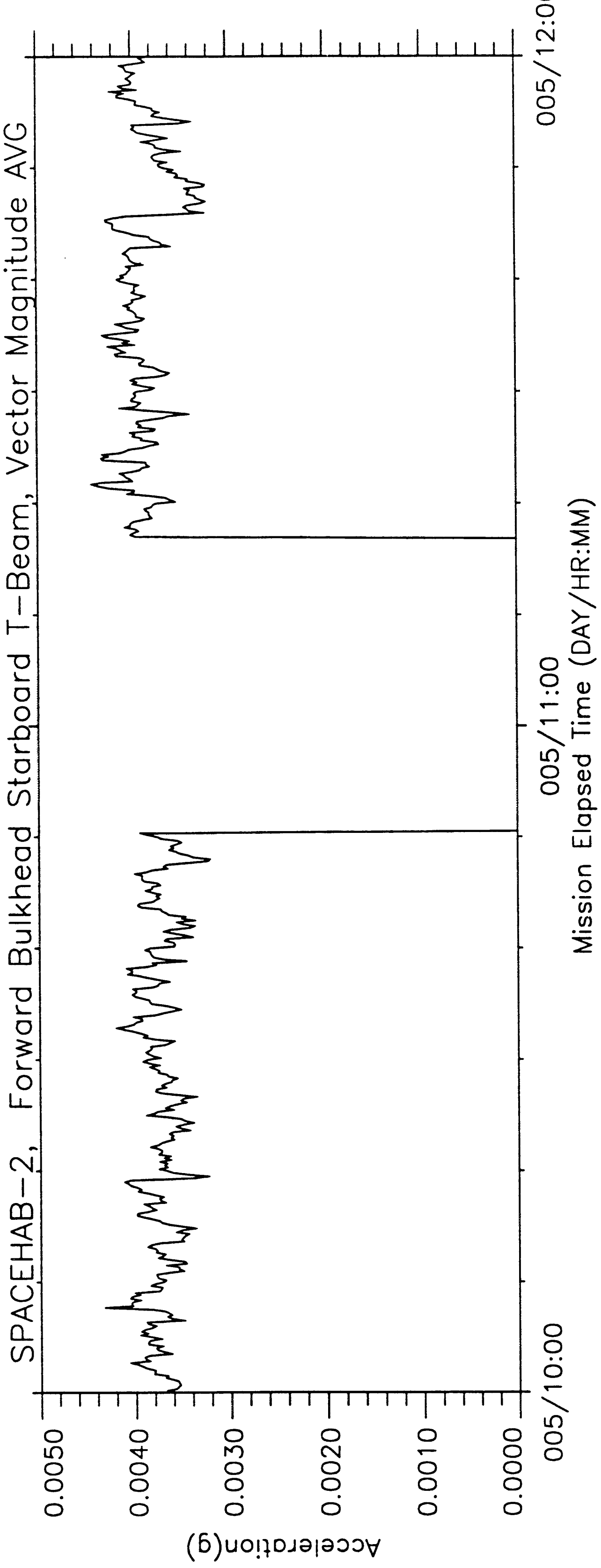
005/10:00
Mission Elapsed Time (DAY/HR:MM)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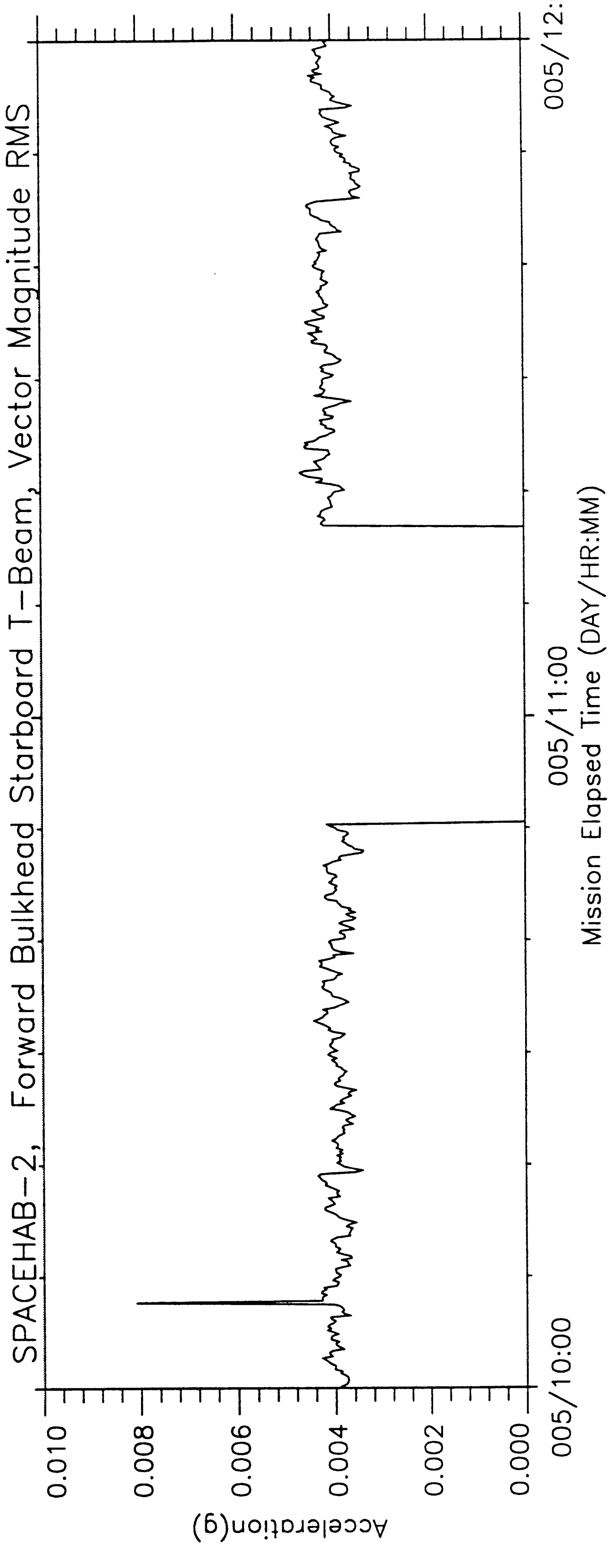
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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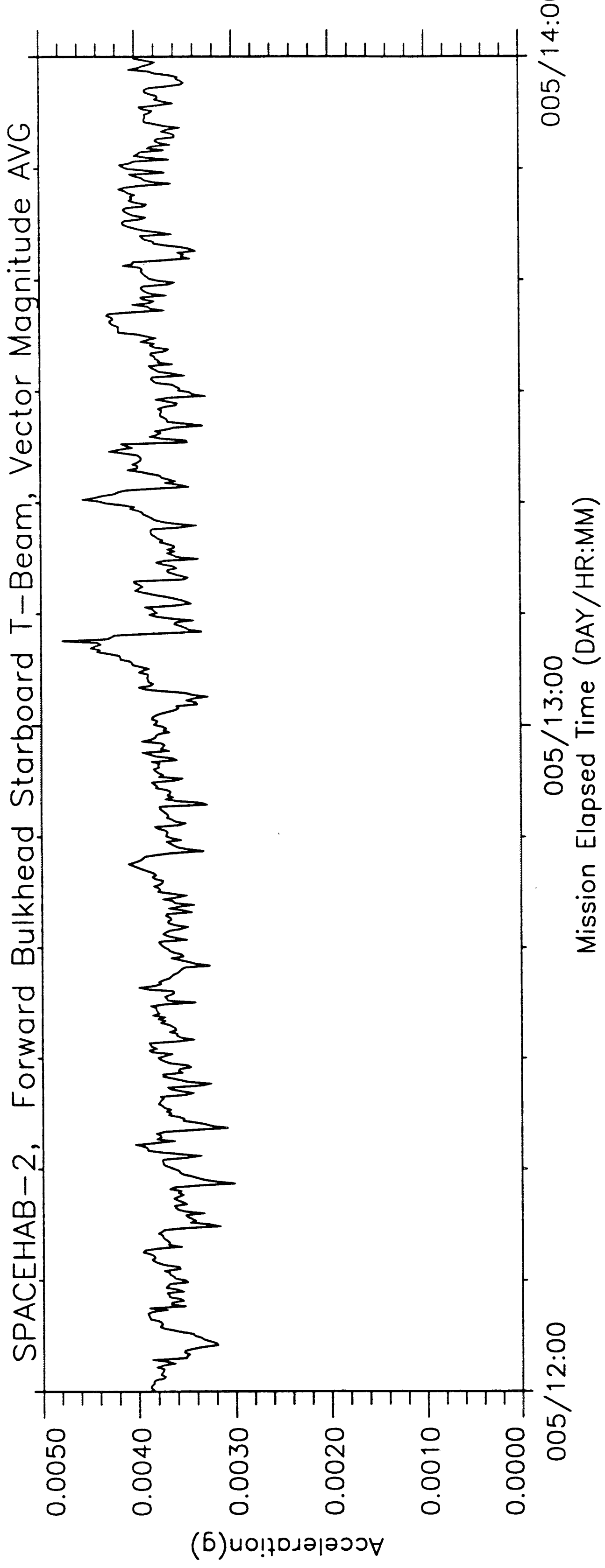
005/12:00
Mission Elapsed Time (DAY/HR:MM)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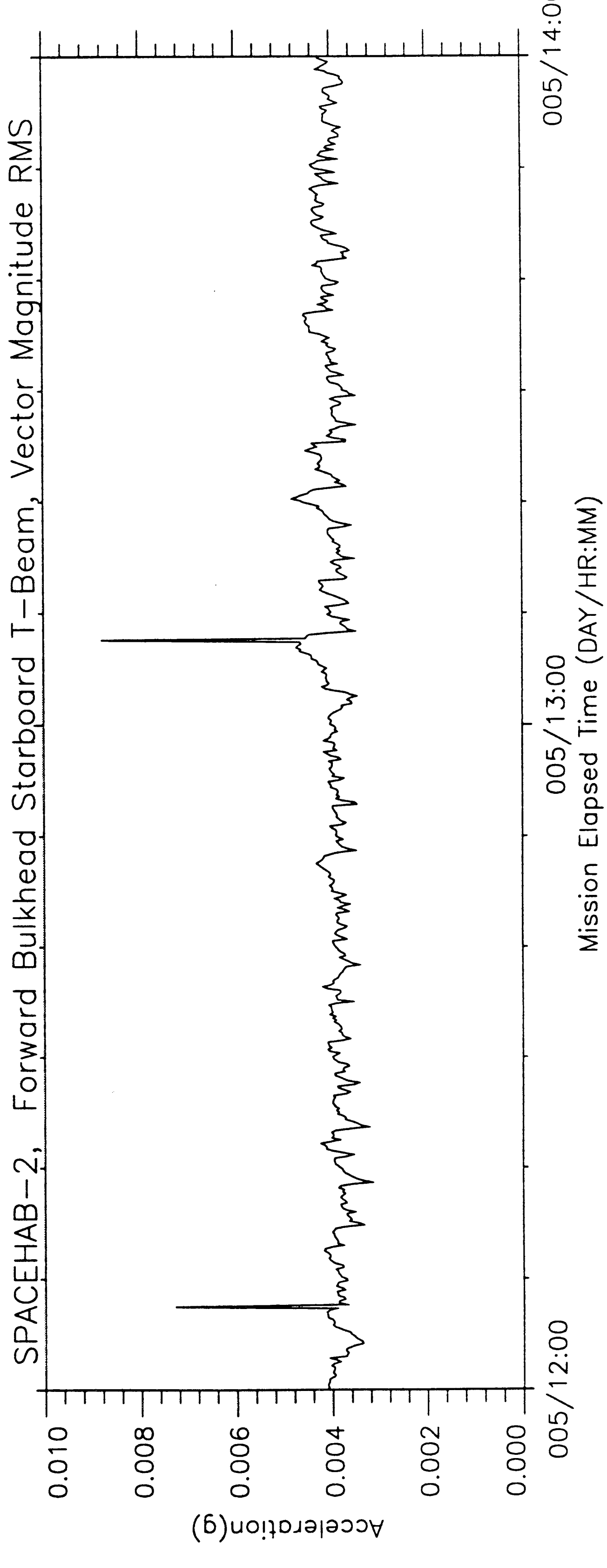
005/14:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
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0.000
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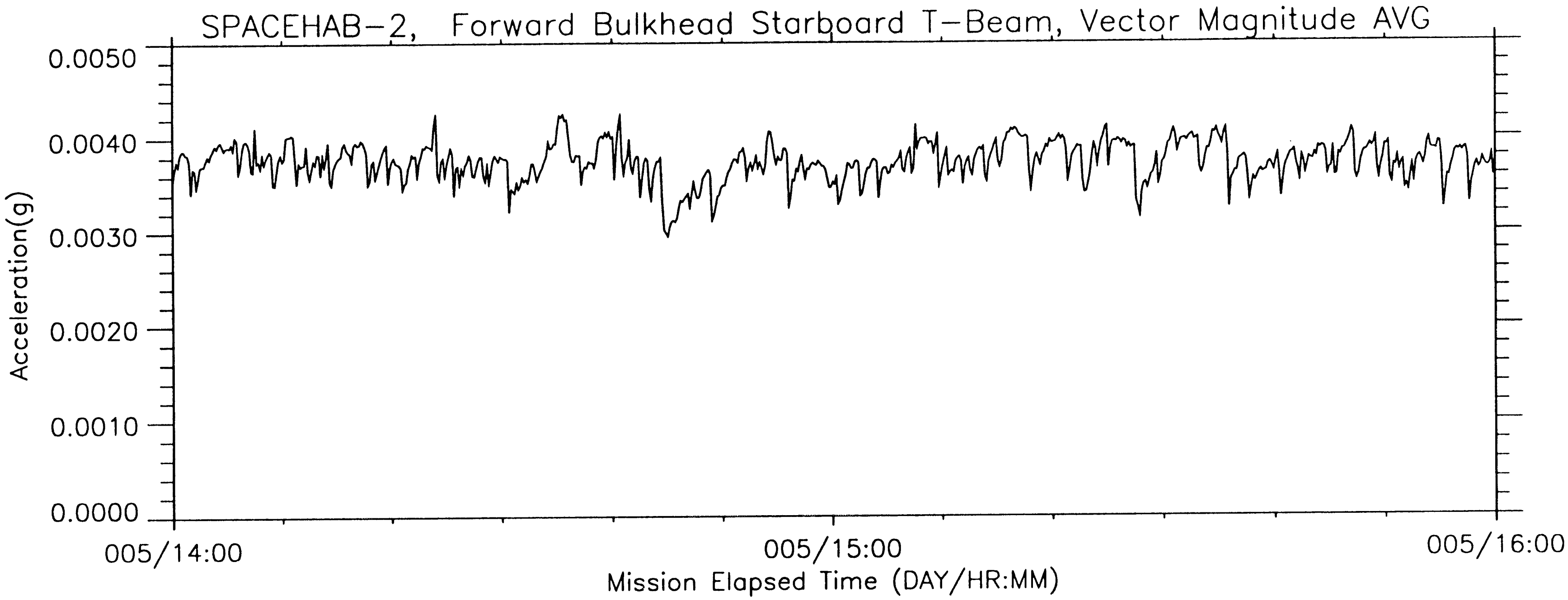
005/13:00
005/14:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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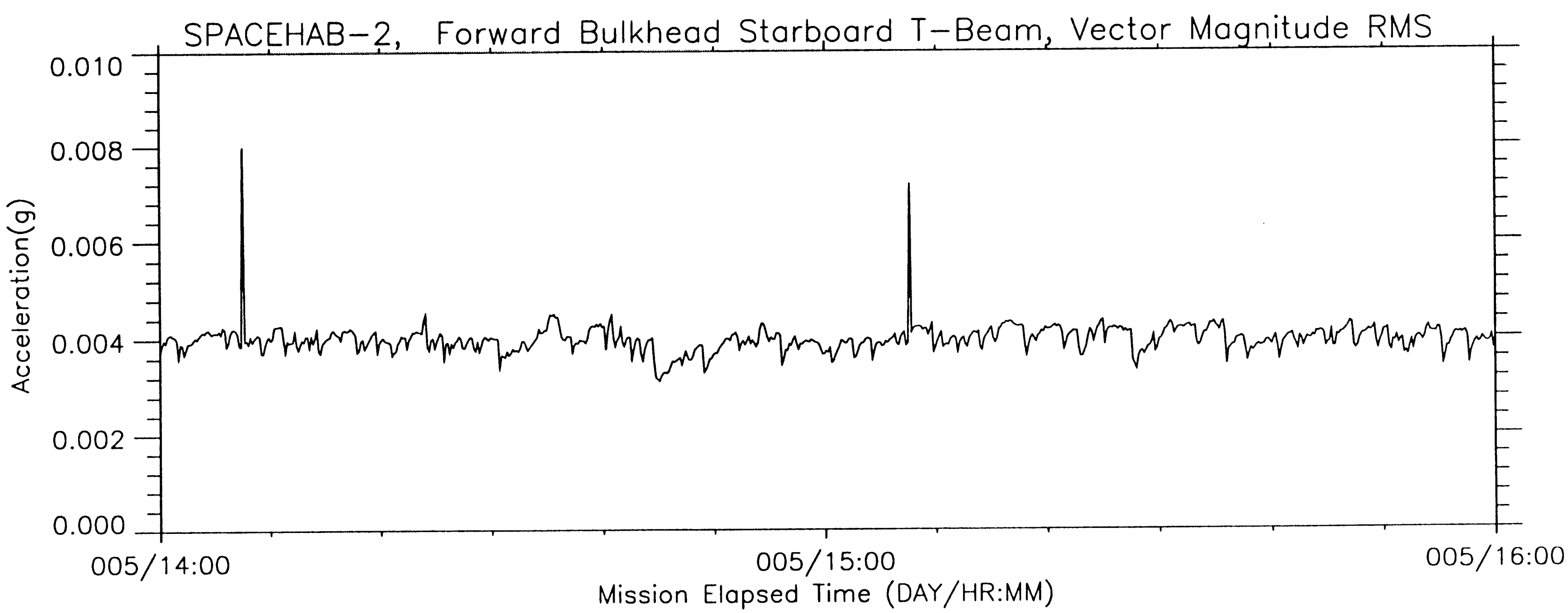
005/16:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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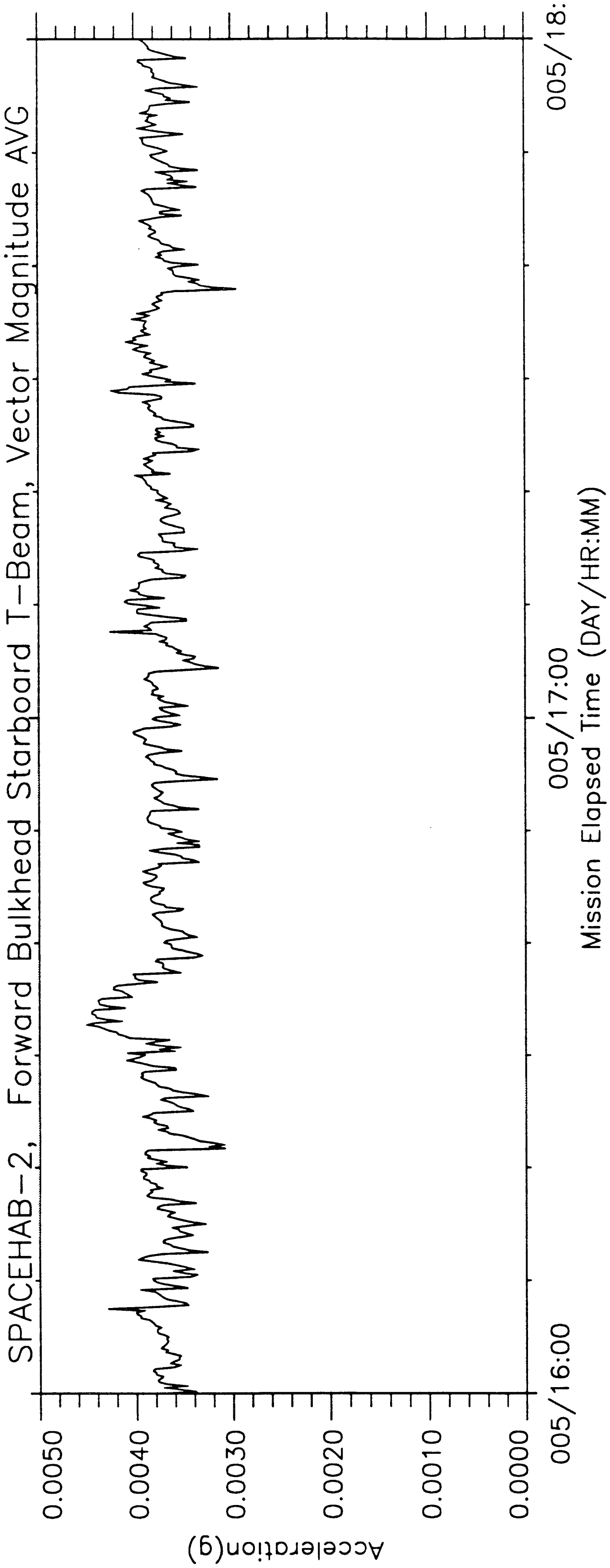
005/16:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude AVG
Acceleration(g)
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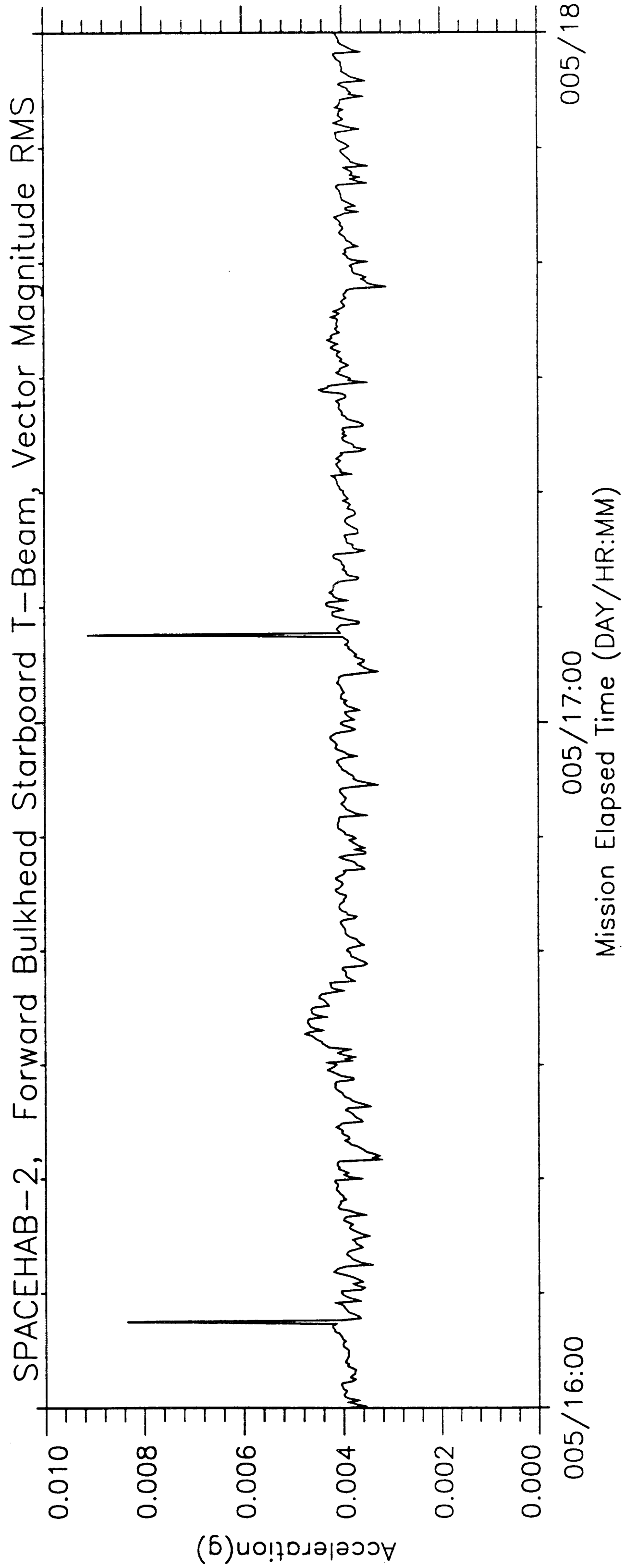
005/17:00
005/18:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude RMS
Acceleration(g)
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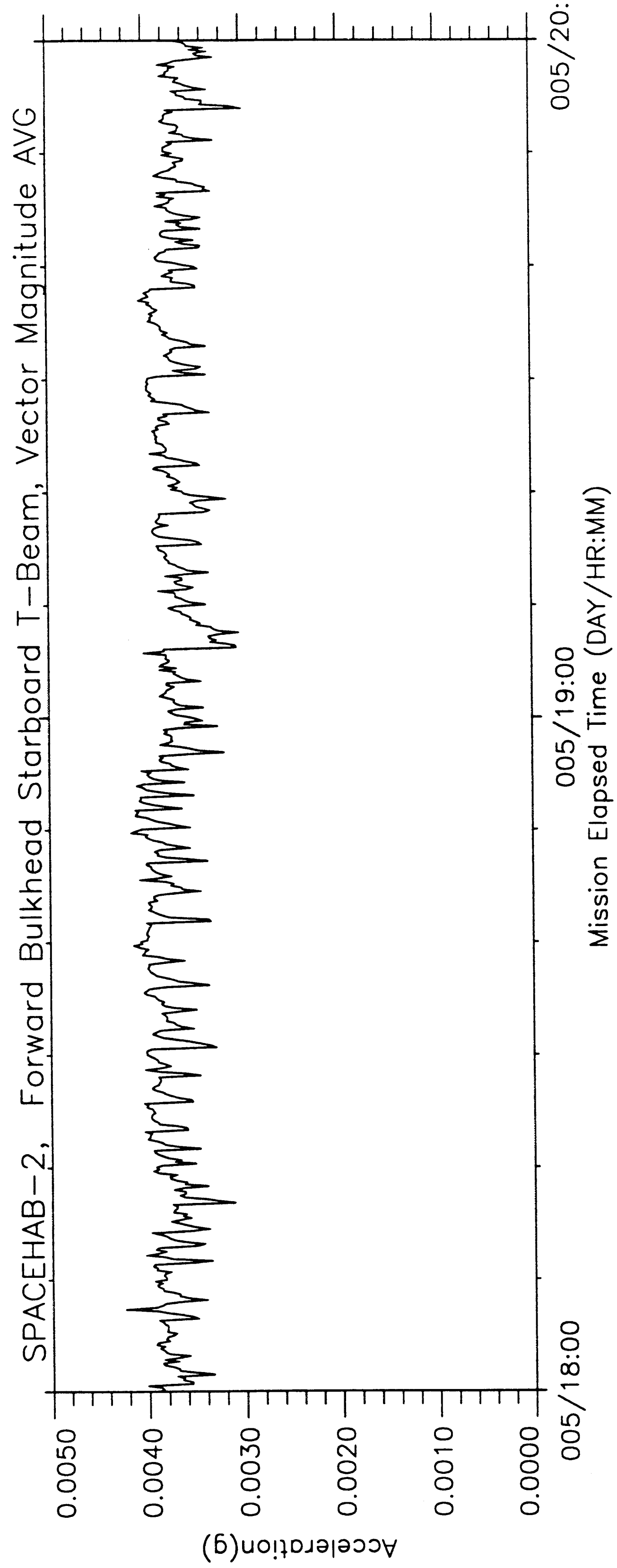
005/17:00
005/18:00
Mission Elapsed Time (DAY/HR:MM)

C-2.


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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0.0010
0.0000
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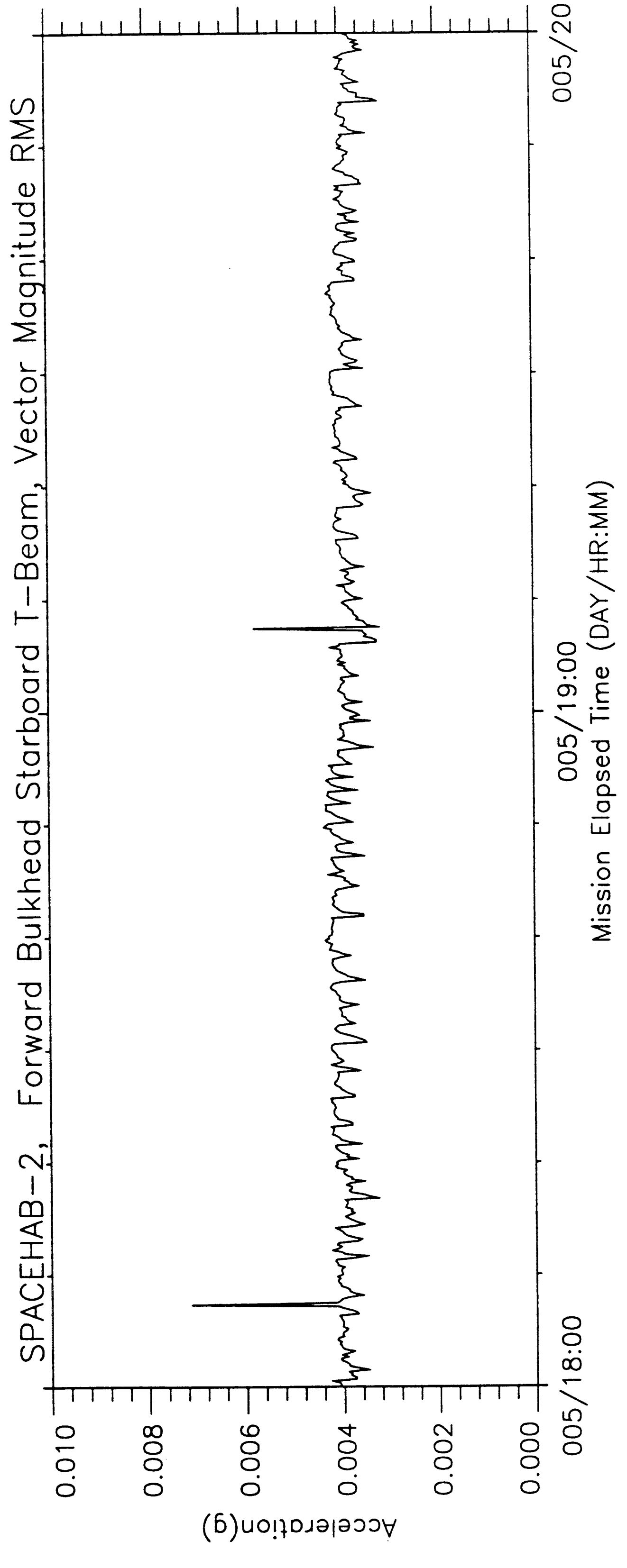
005/19:00
005/20:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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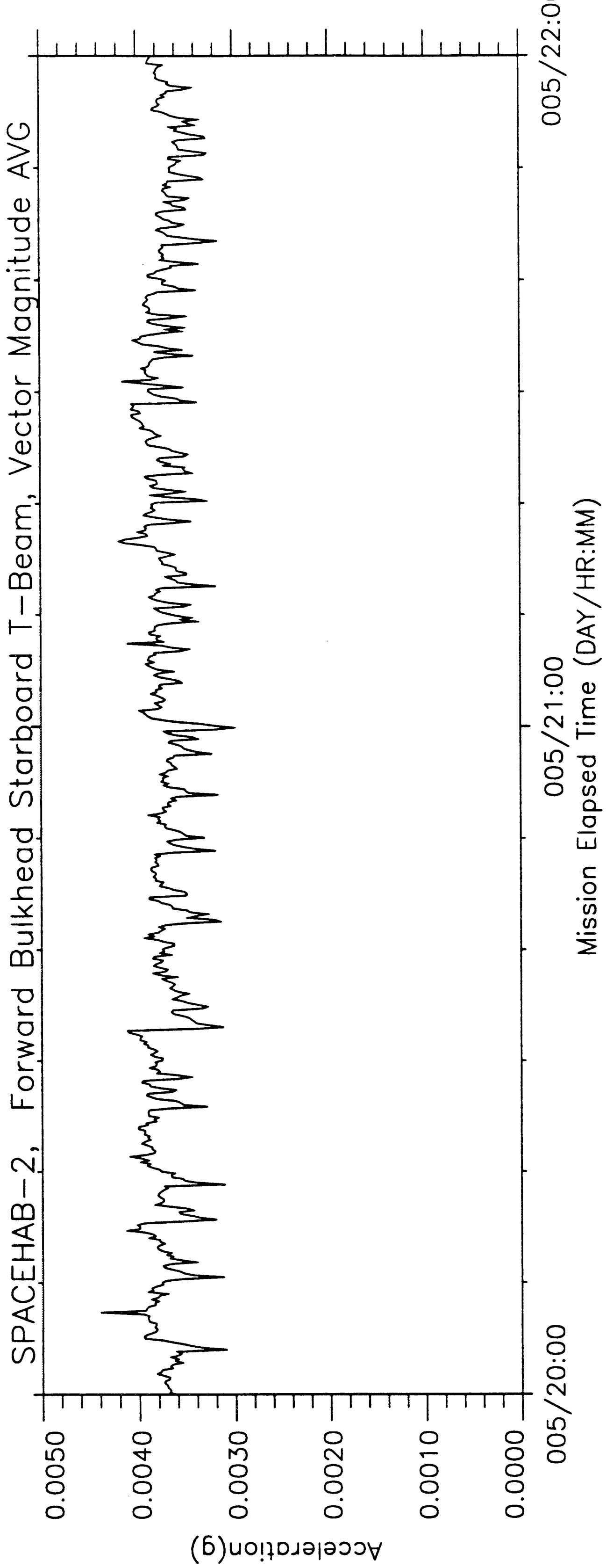
005/20:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude AVG
Acceleration(g)
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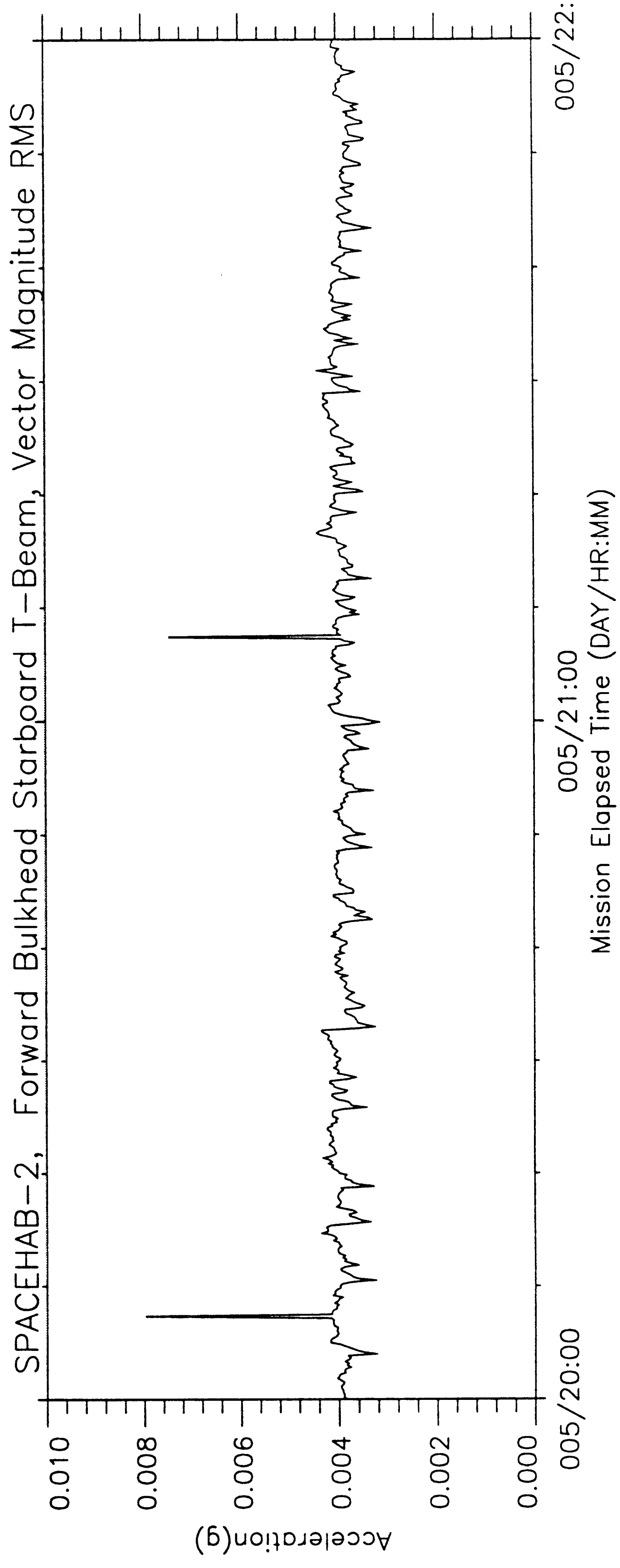
005/21:00
005/22:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude RMS
Acceleration(g)
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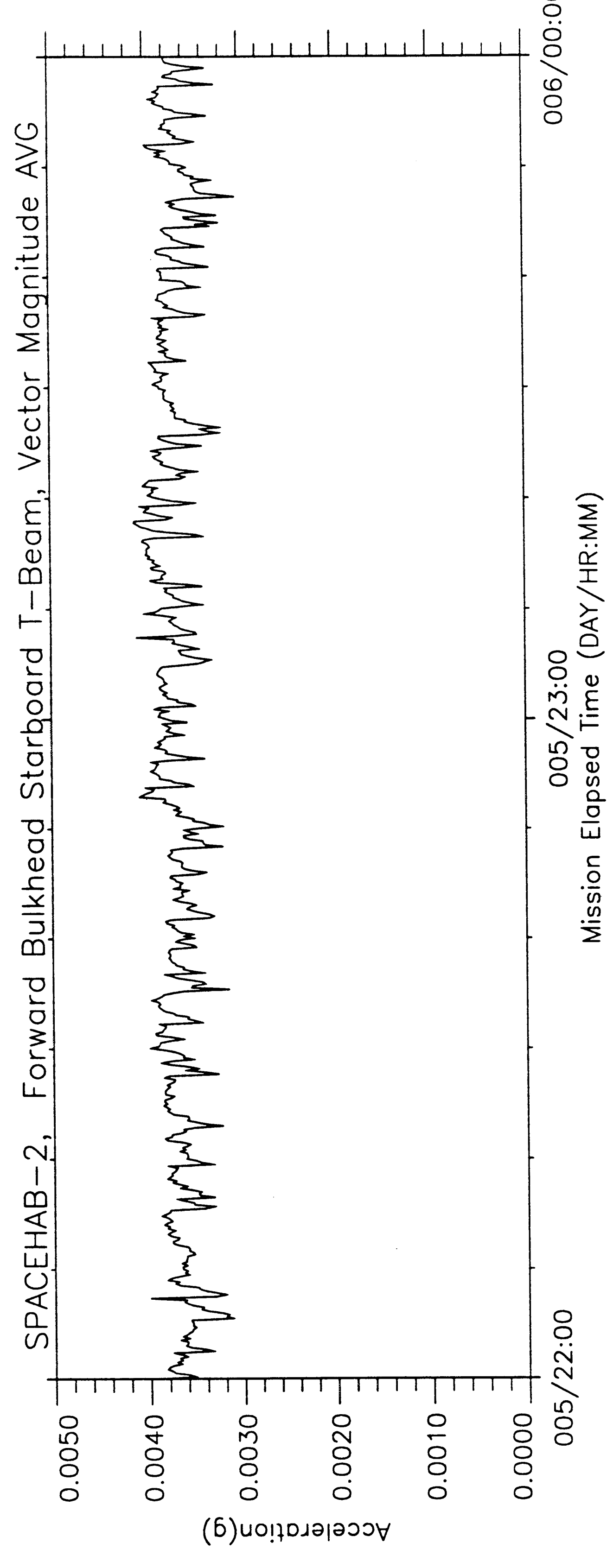
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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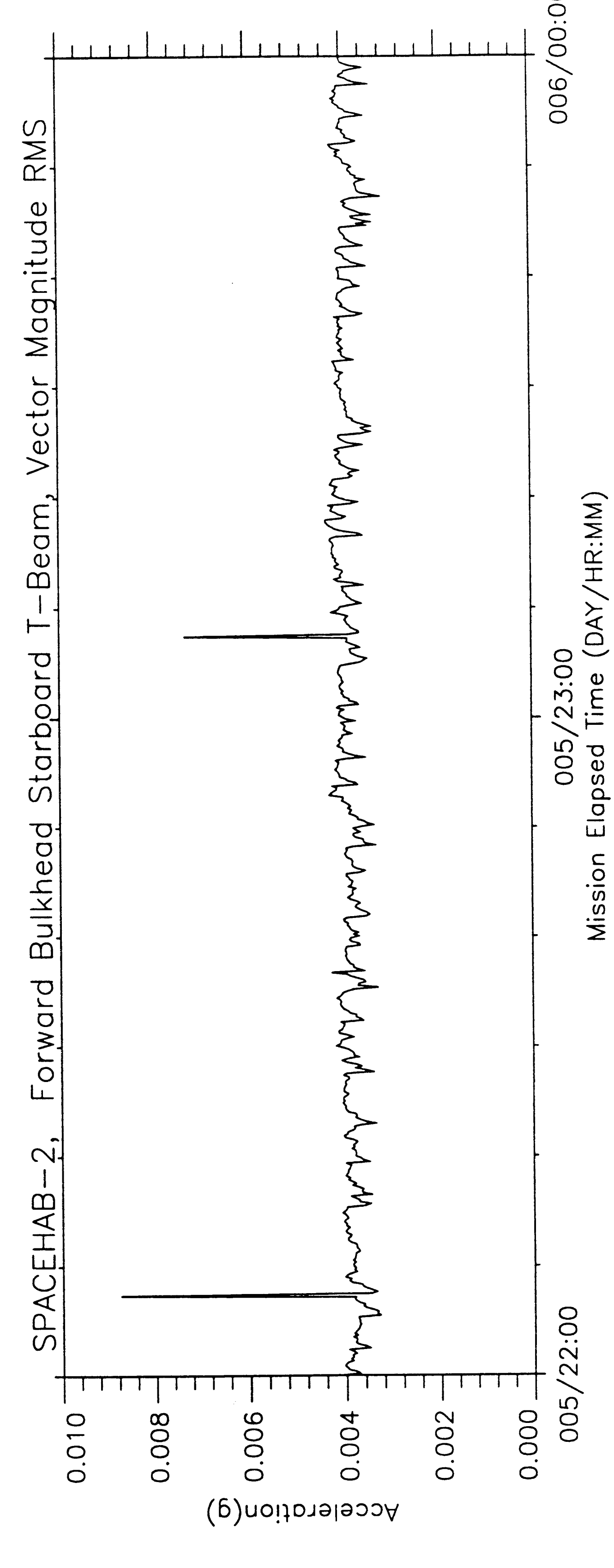
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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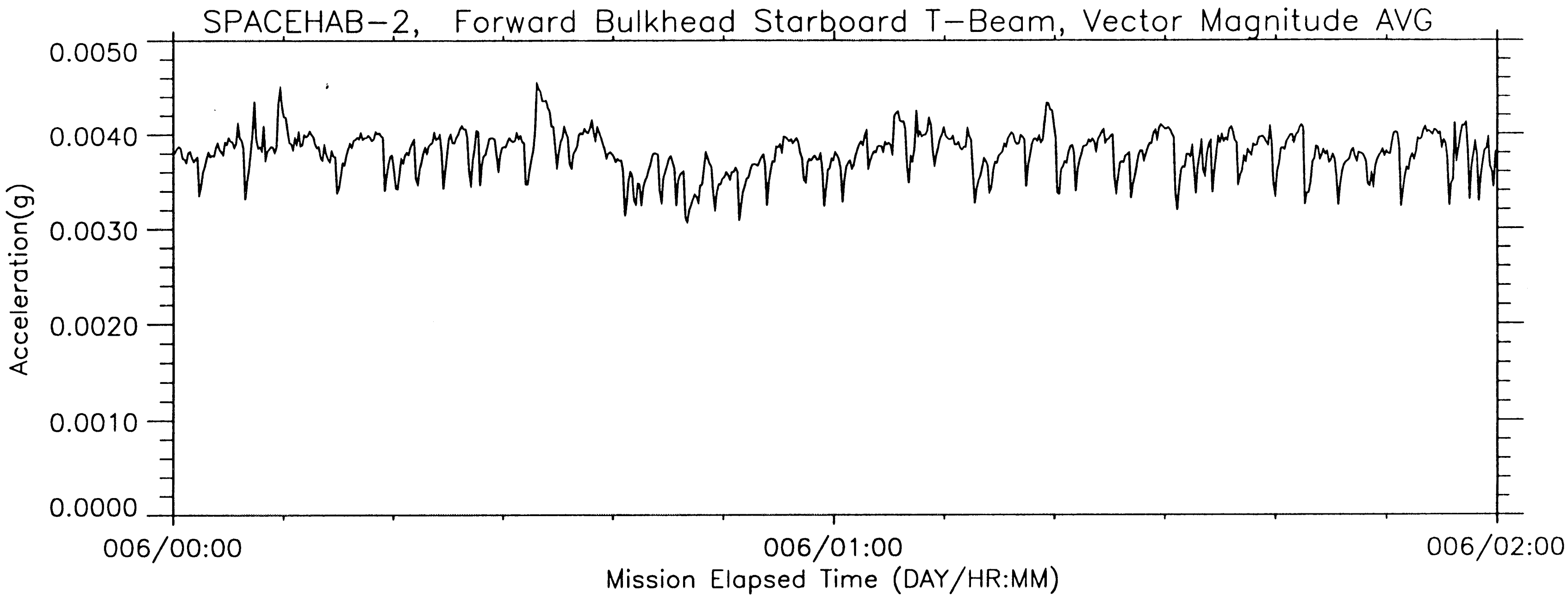
005/22:00
005/23:00
006/00:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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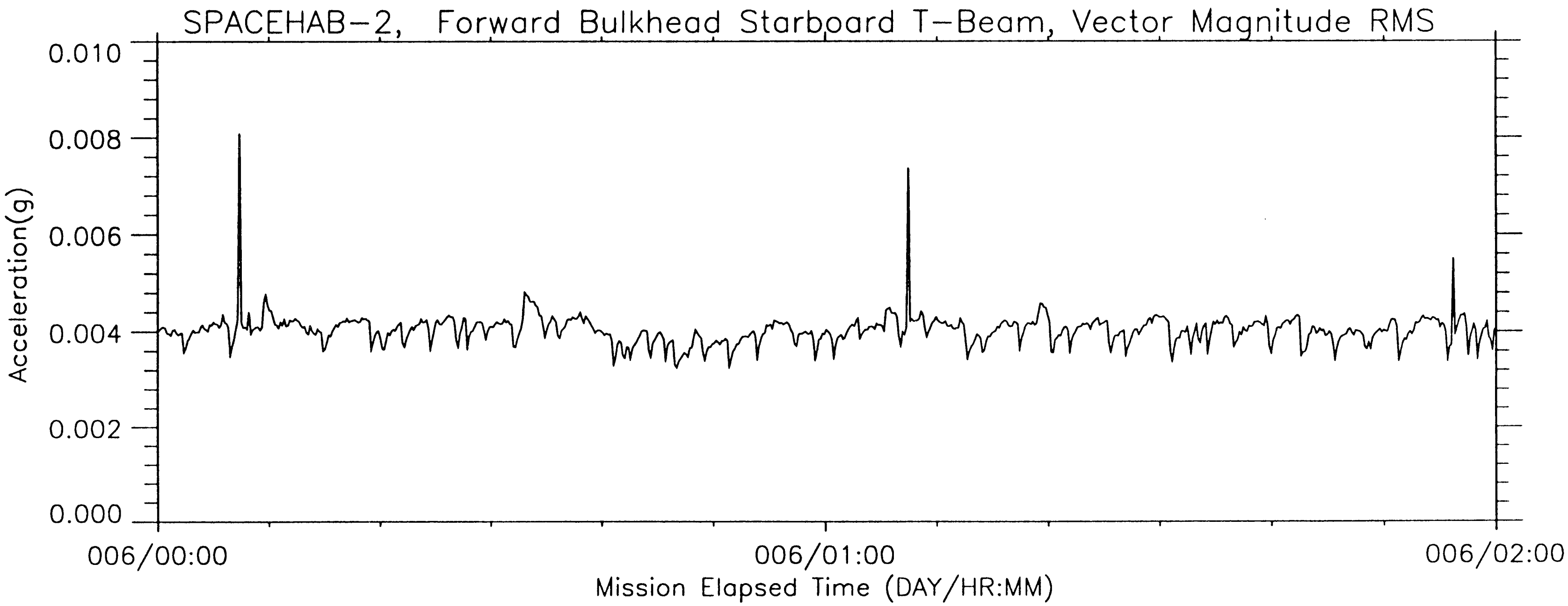
006/02:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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0.008
0.006
0.004
0.002
0.000
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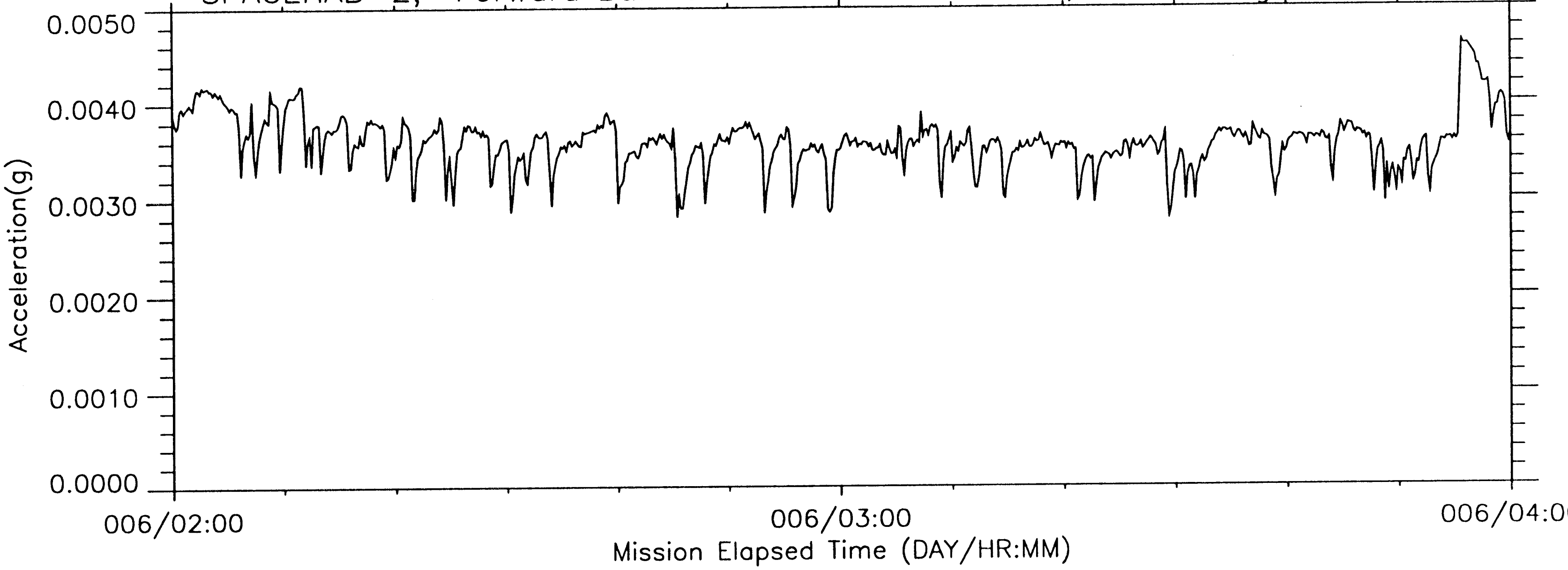
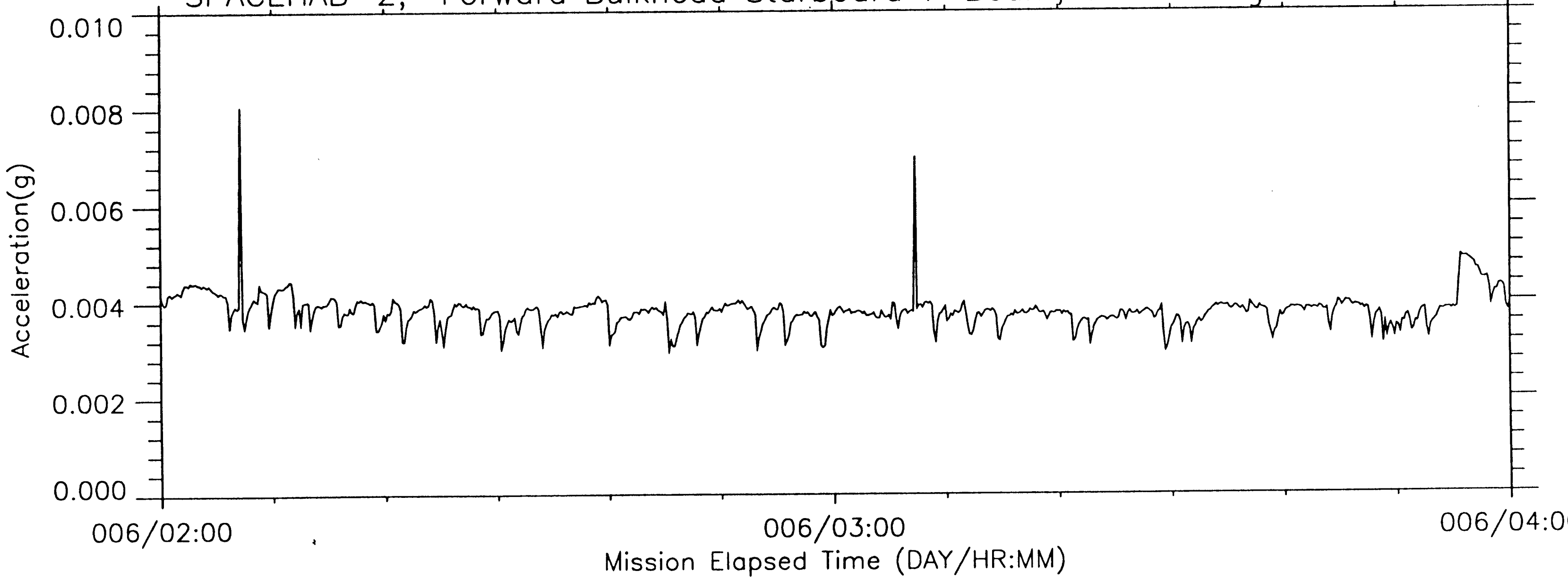
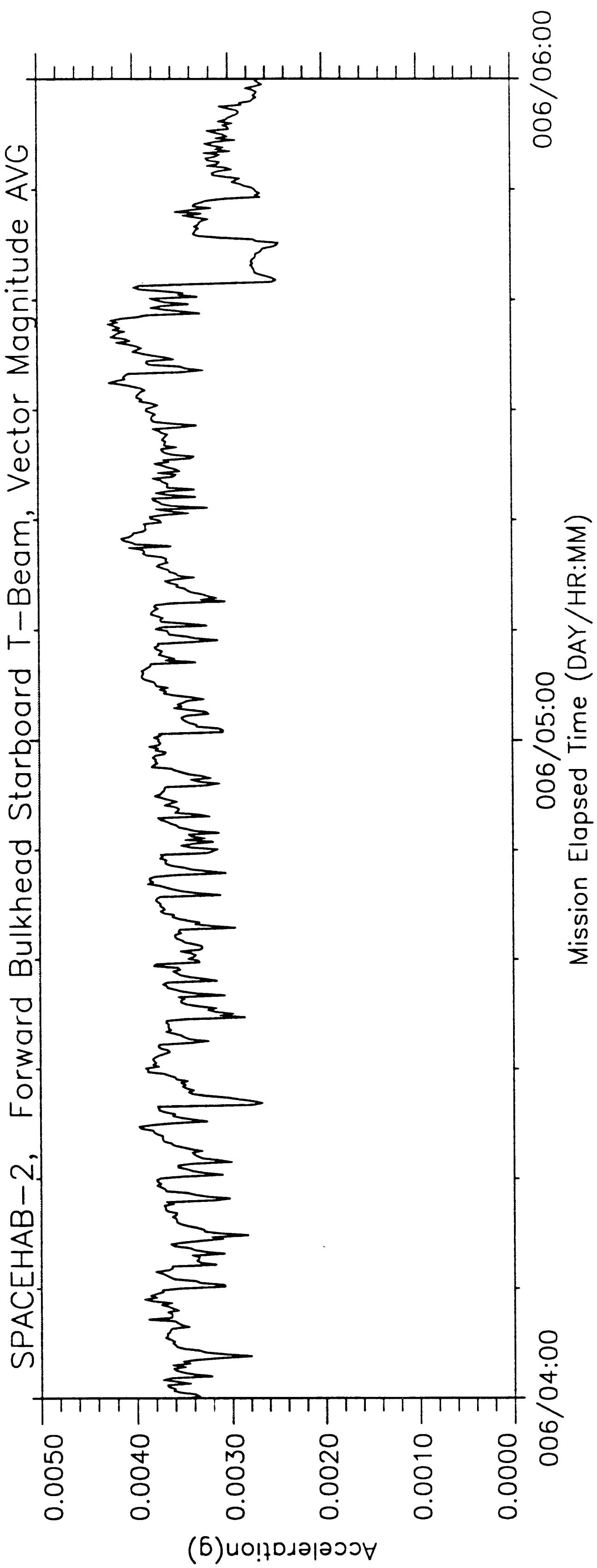
006/02:00
Mission Elapsed Time (DAY/HR:MM)

SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG



SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS





SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
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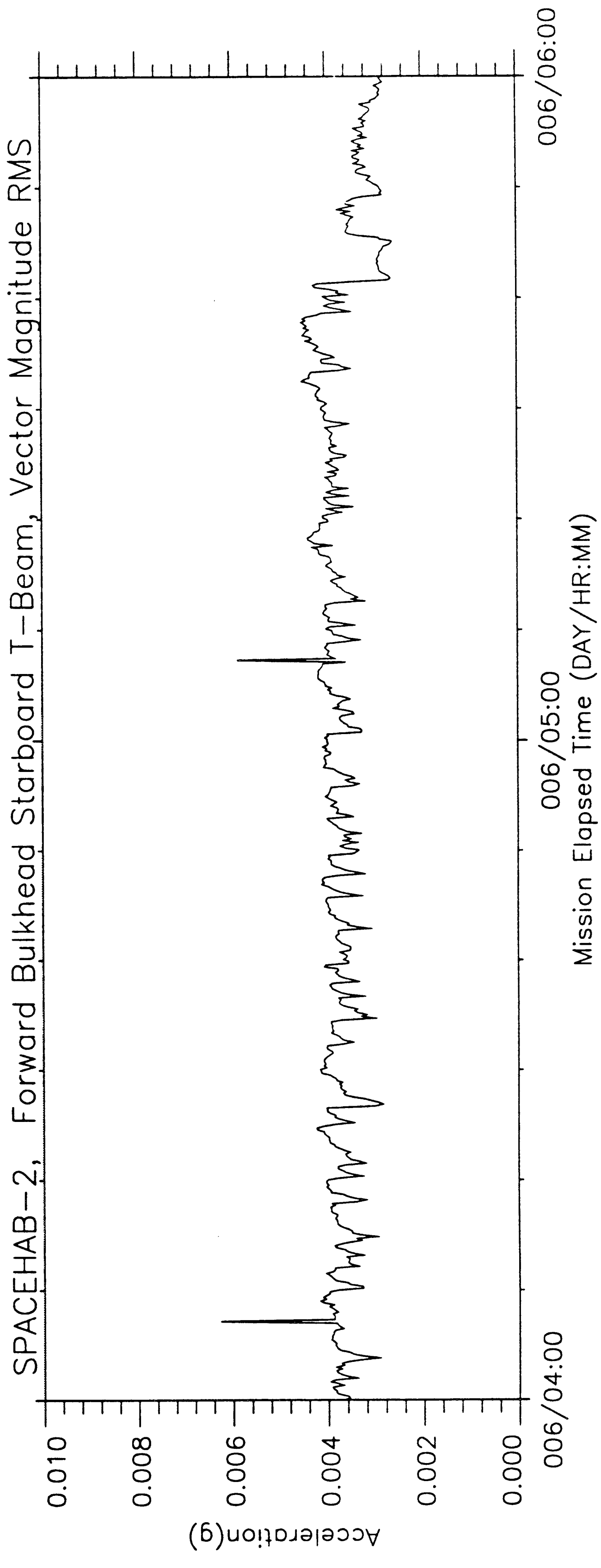
Mission Elapsed Time (DAY/HR:MM)



SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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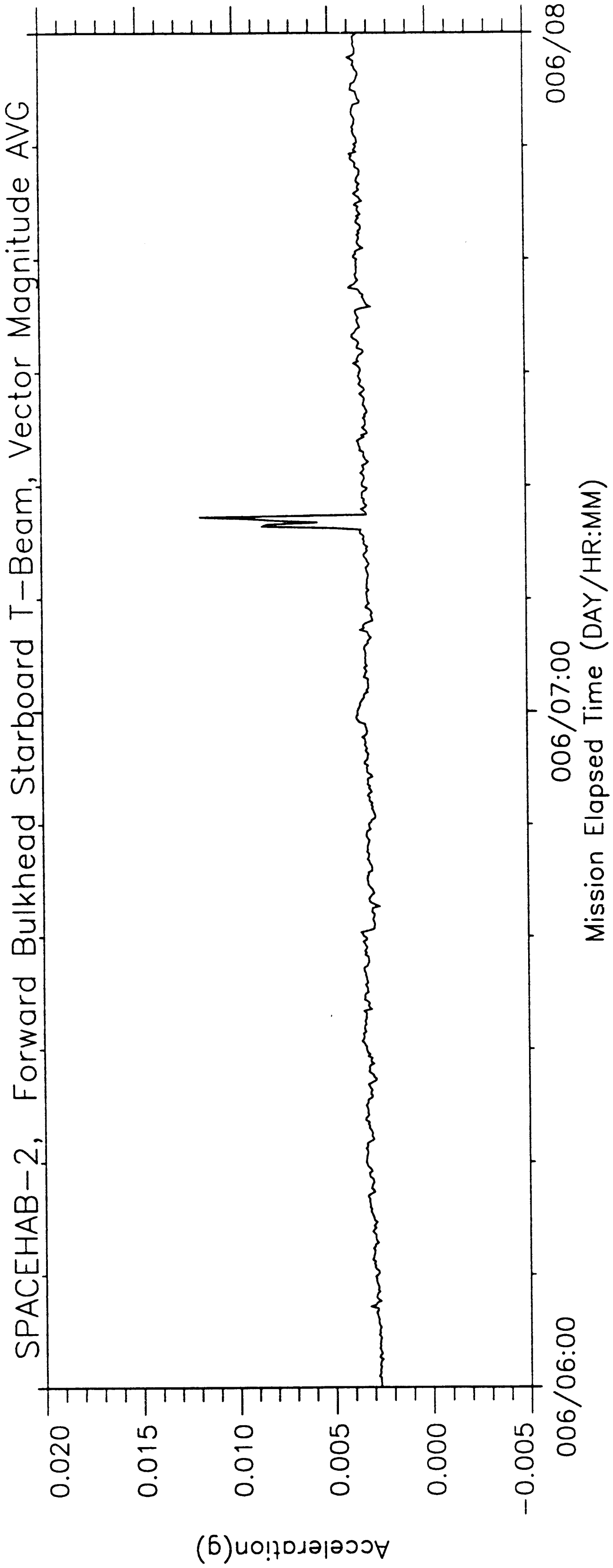
Mission Elapsed Time (DAY/HR:MM)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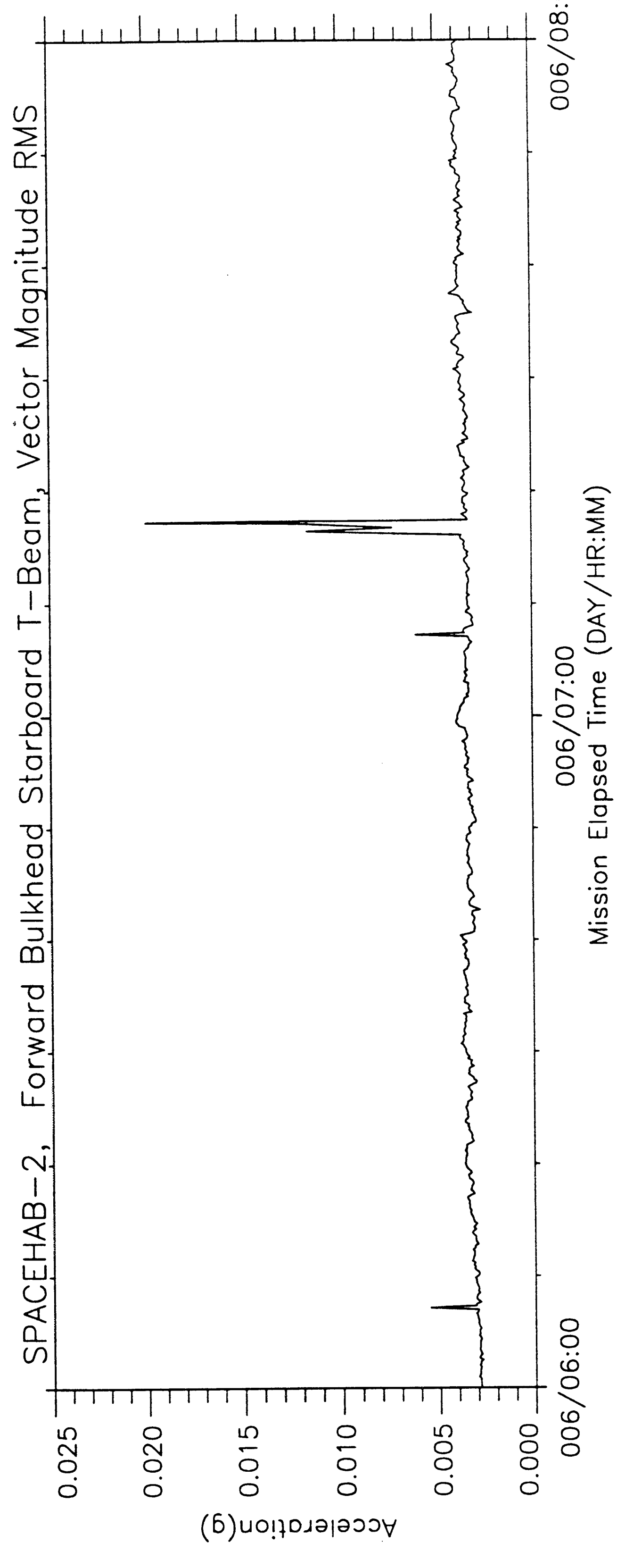
Mission Elapsed Time (DAY/HR:MM)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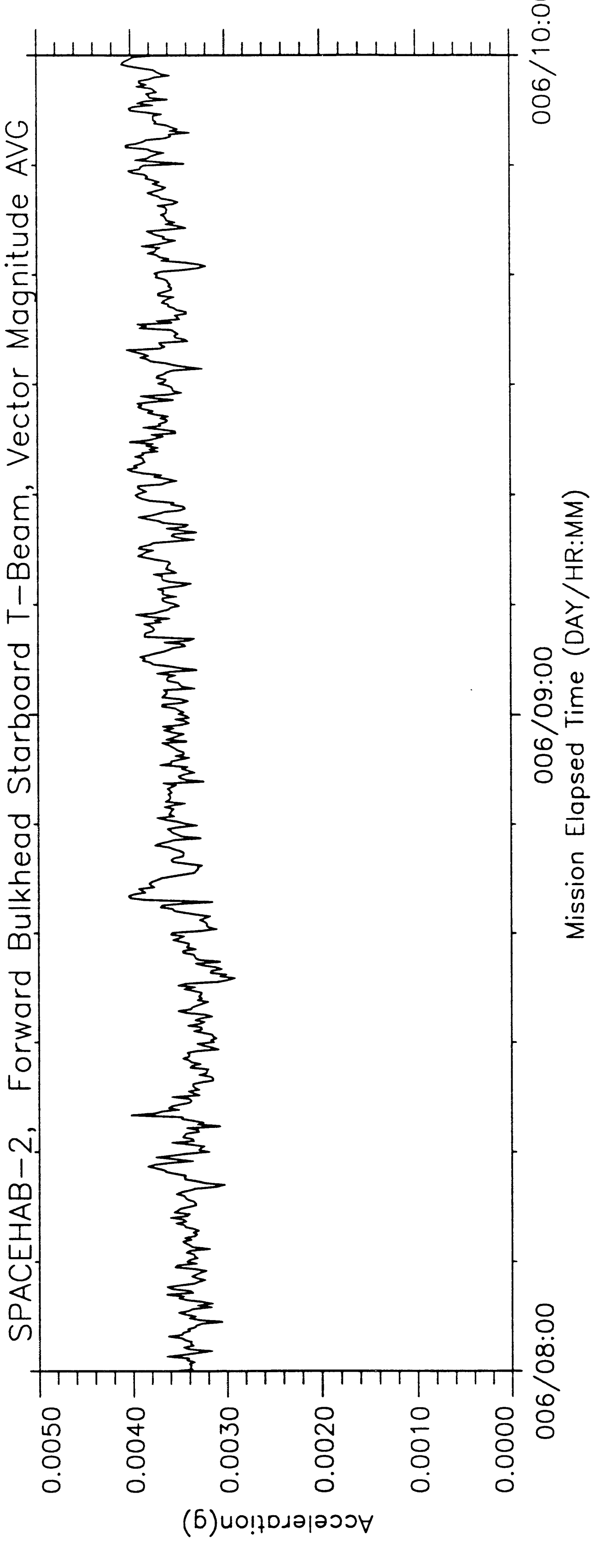
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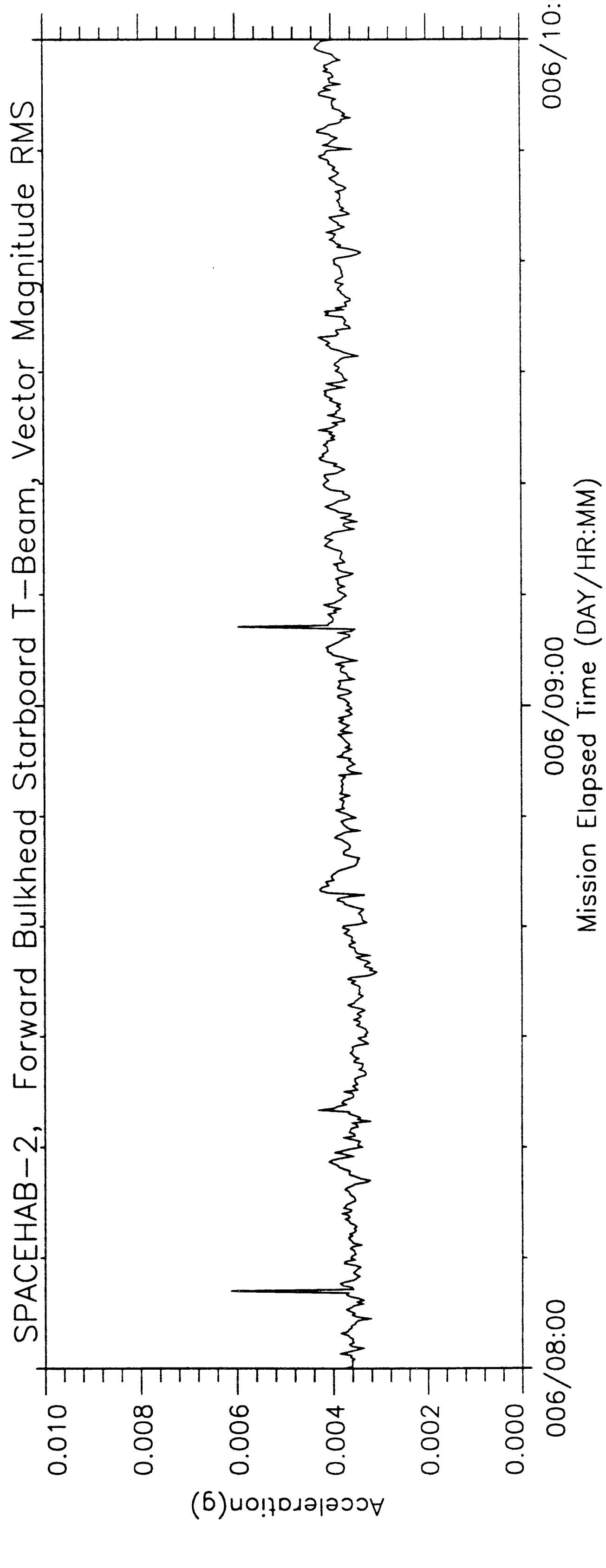
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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0.002
0.000
006/08:00
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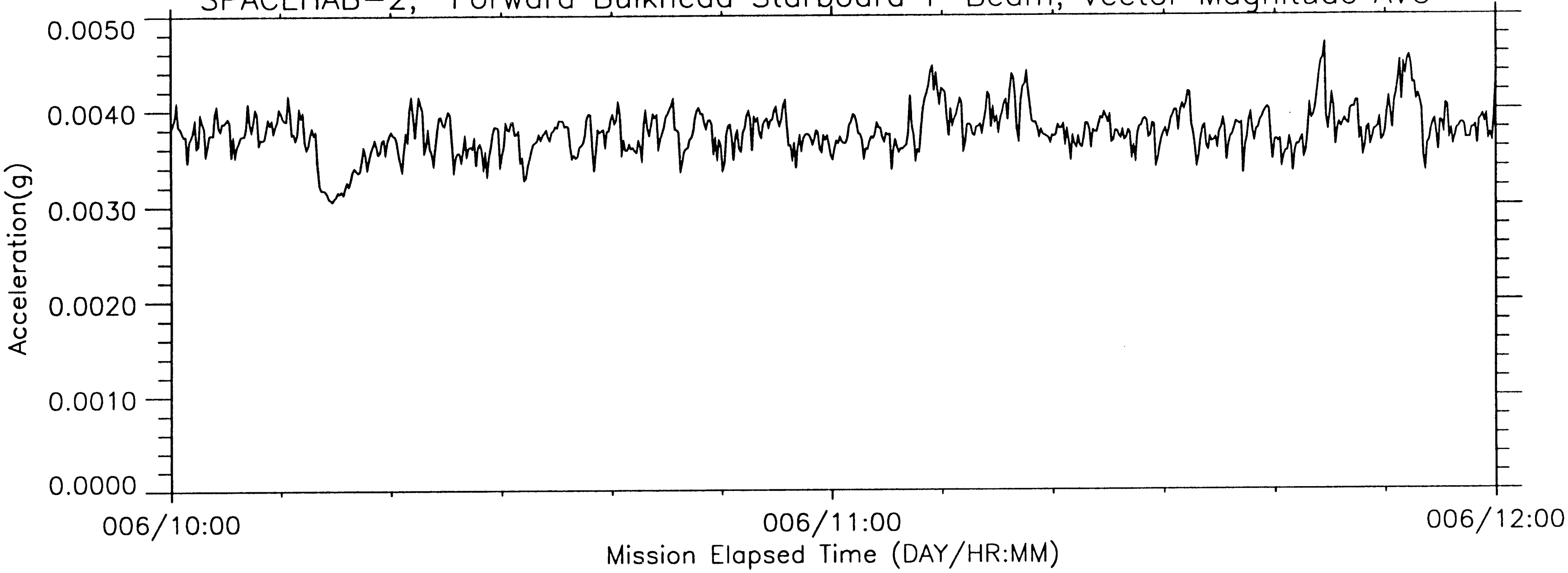
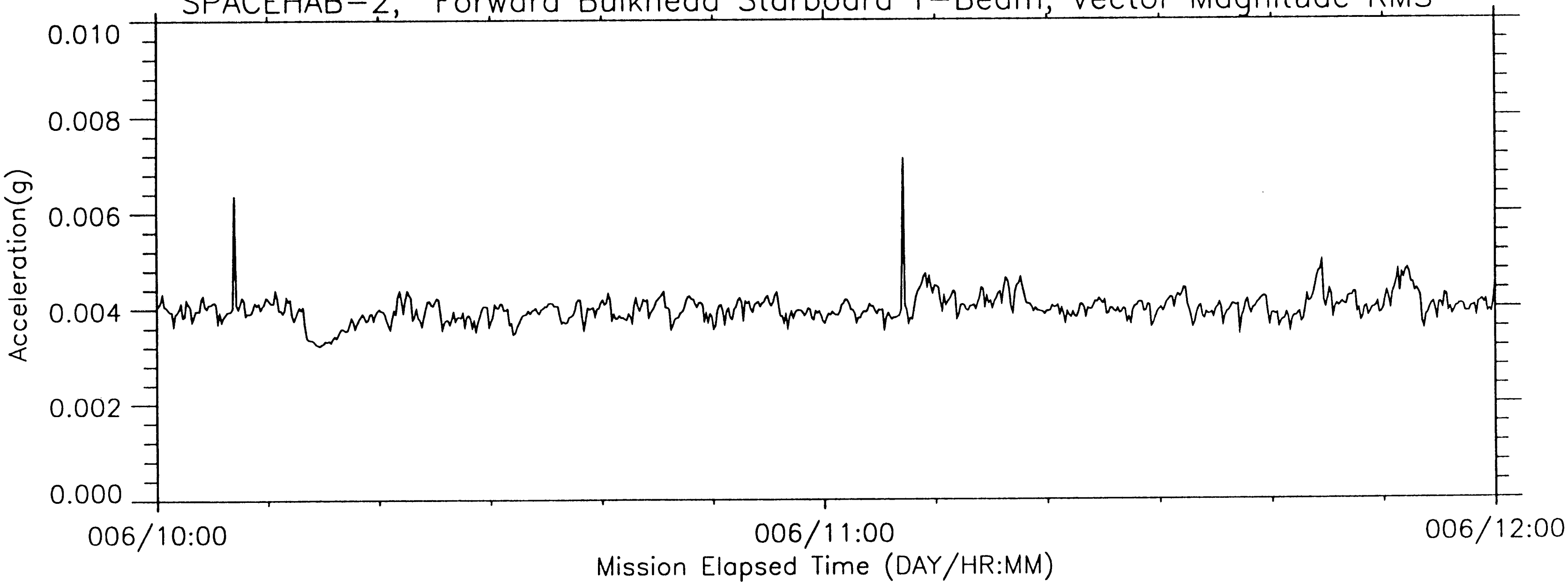
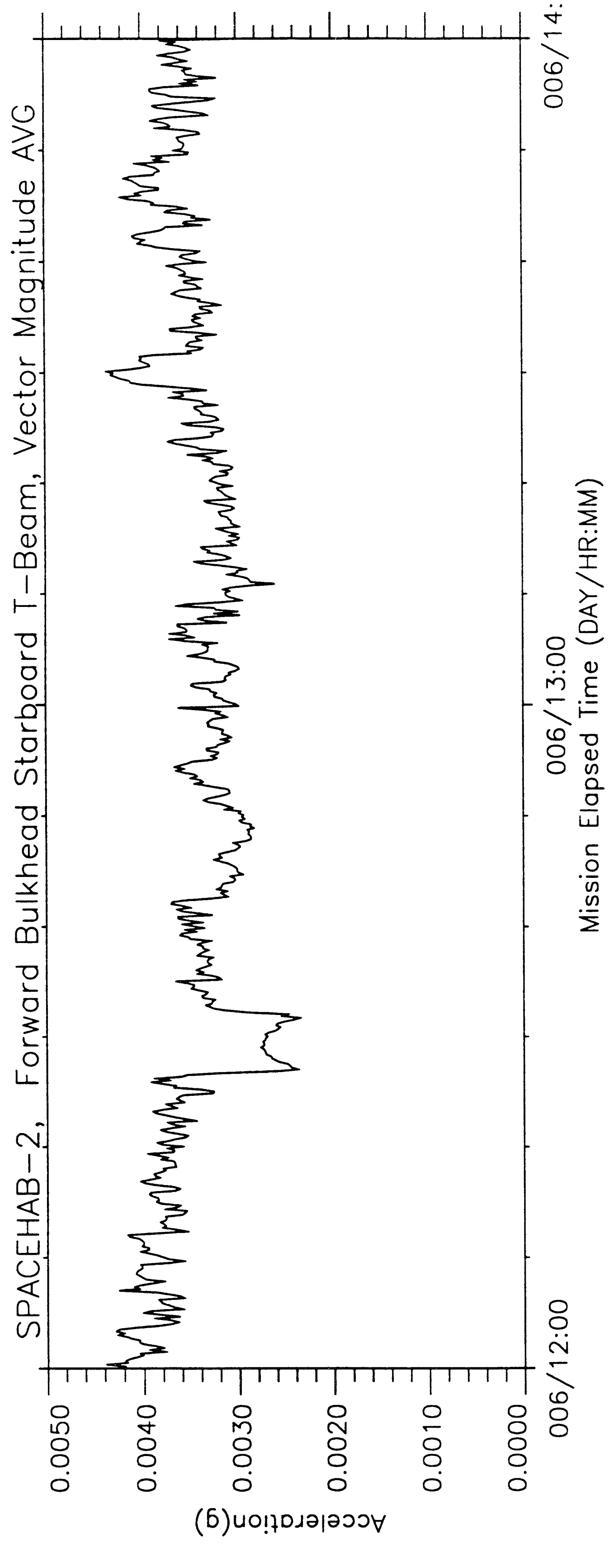
006/10:00
Mission Elapsed Time (DAY/HR:MM)

SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG



SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS




SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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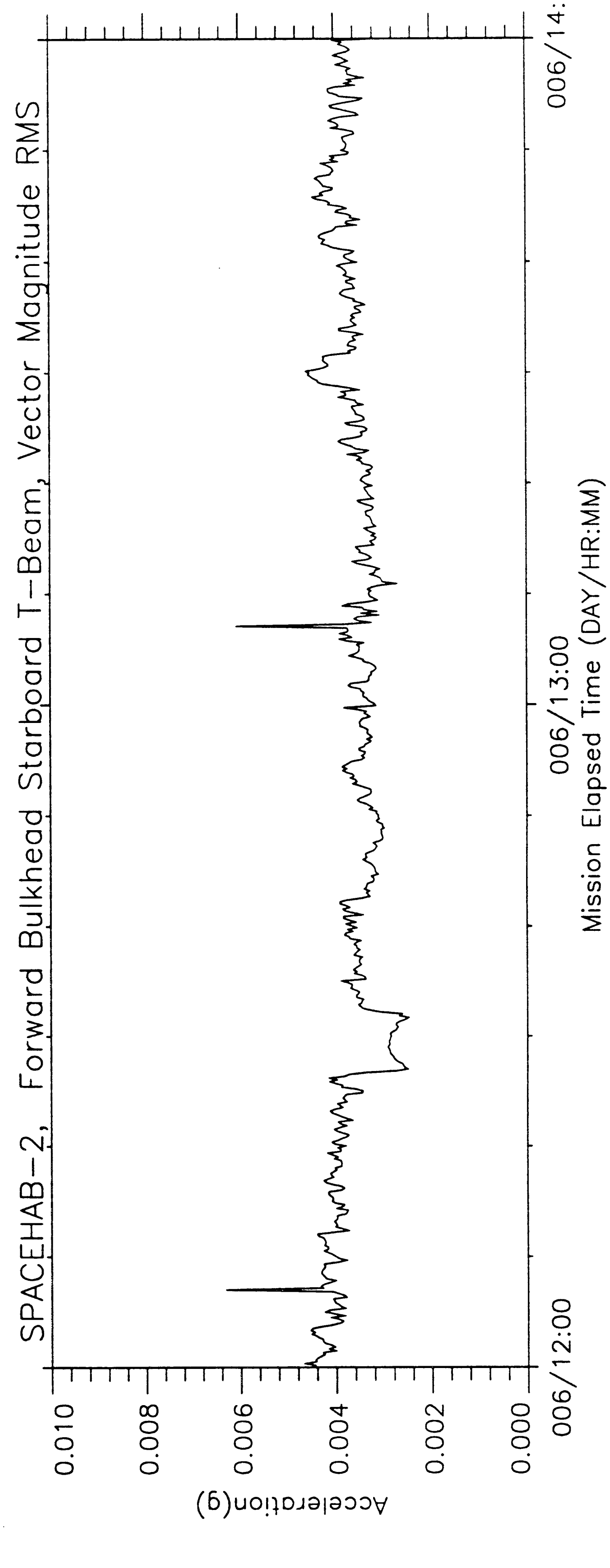
006/14:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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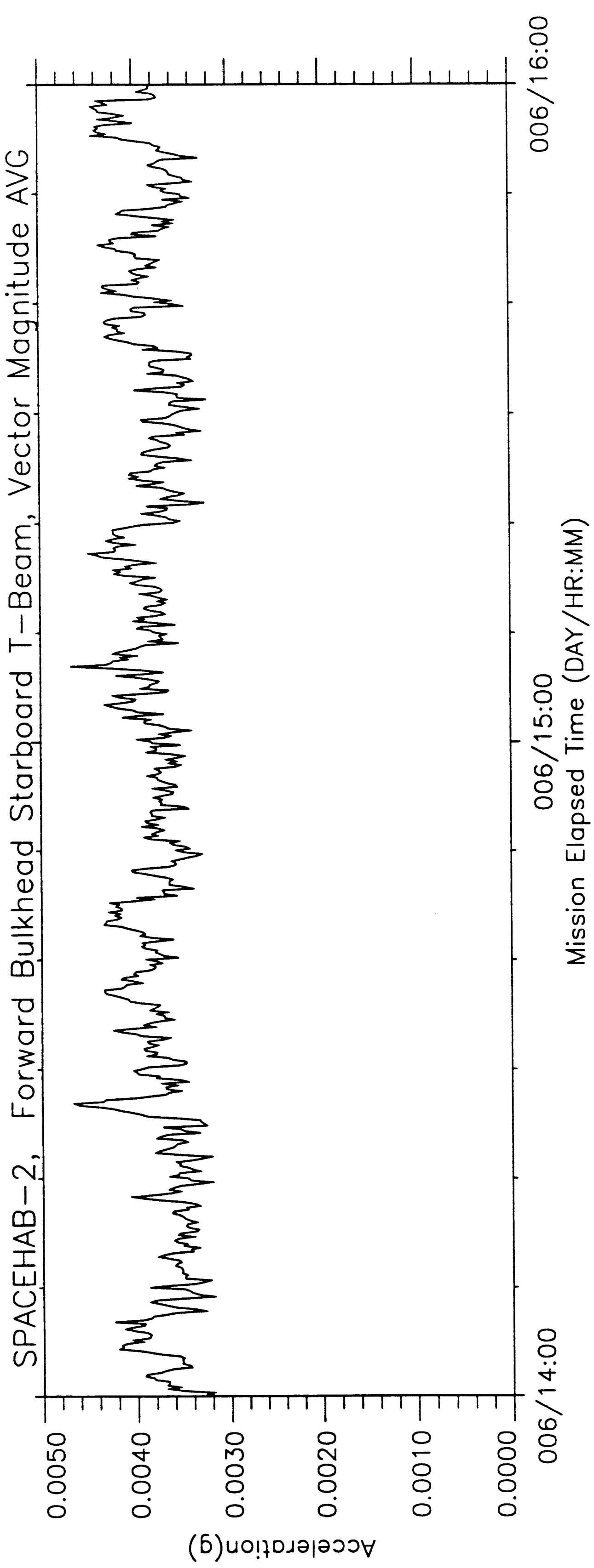
006/14:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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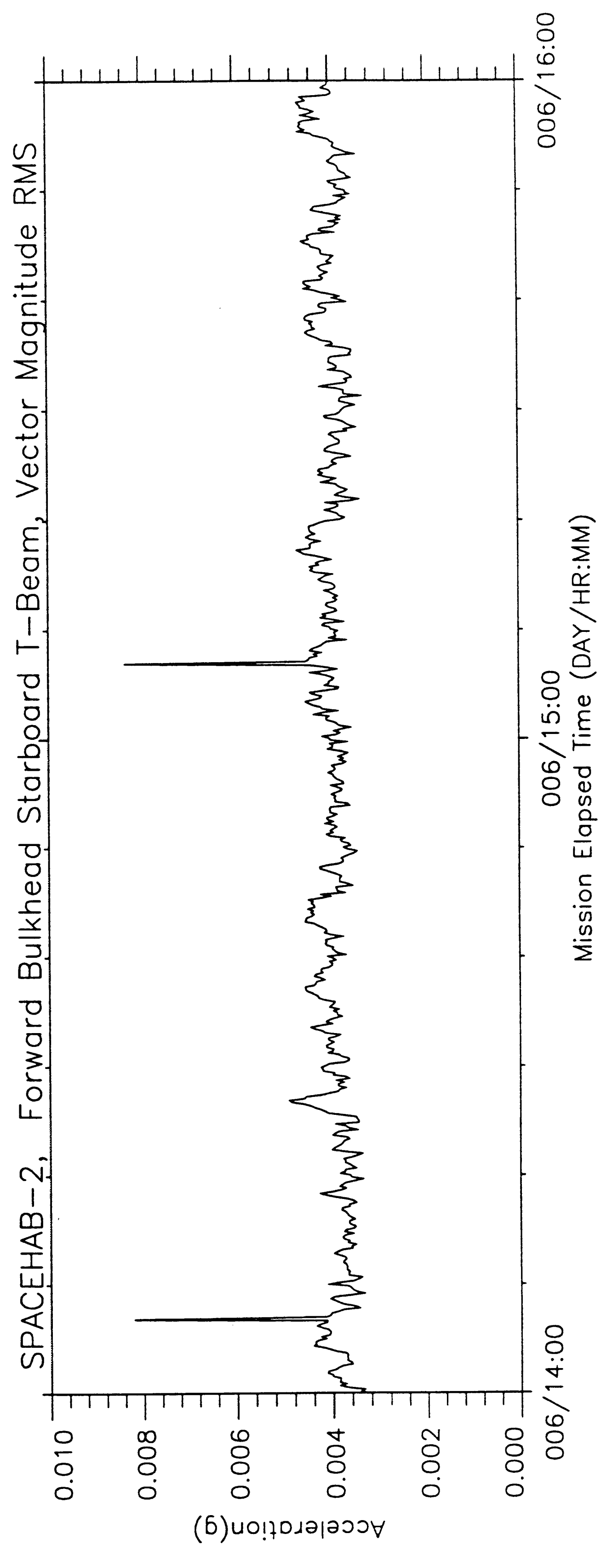
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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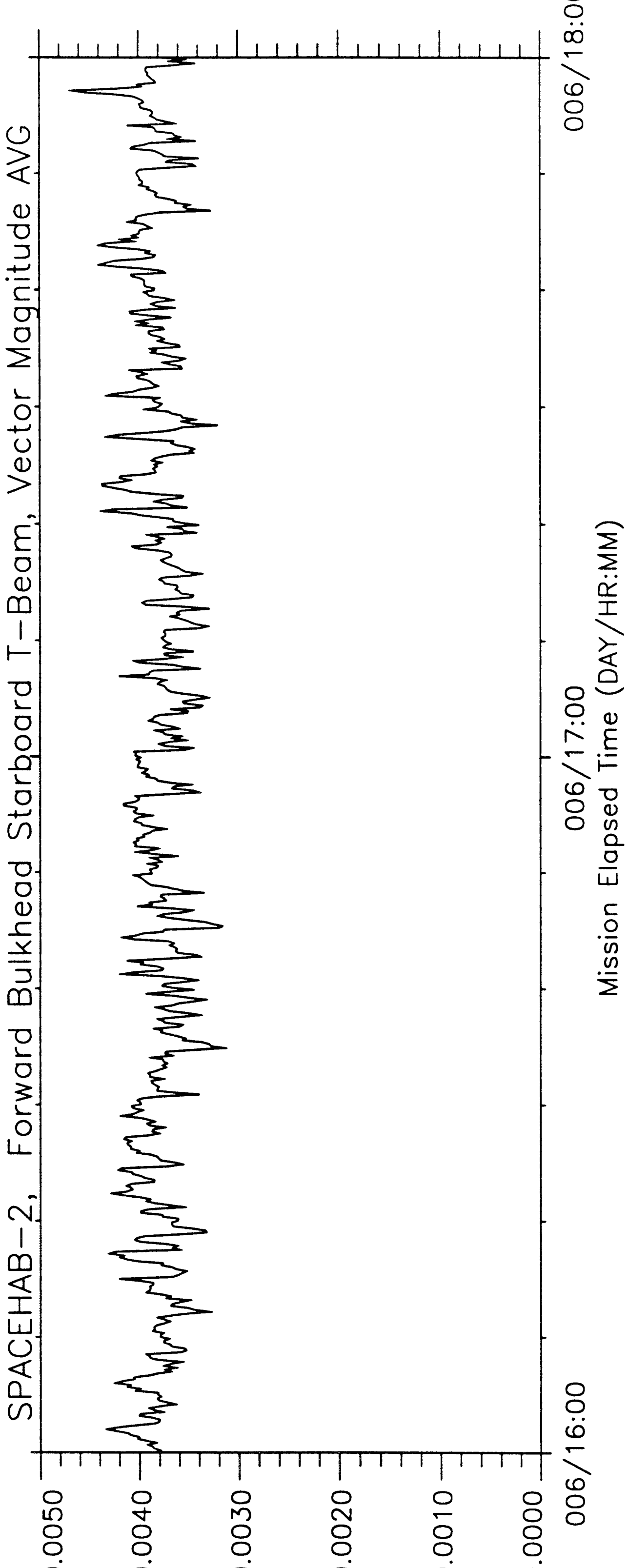
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude AVG
Acceleration(g)
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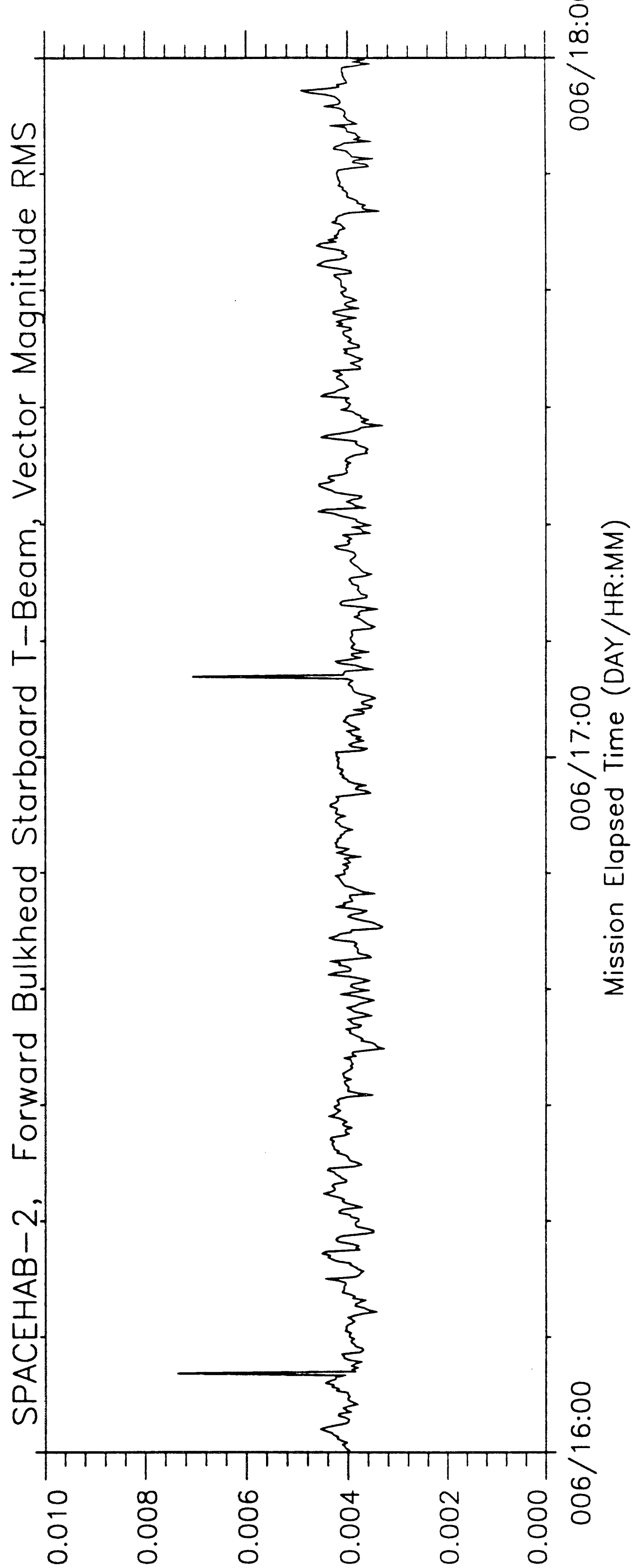
006/18:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude RMS
Acceleration(g)
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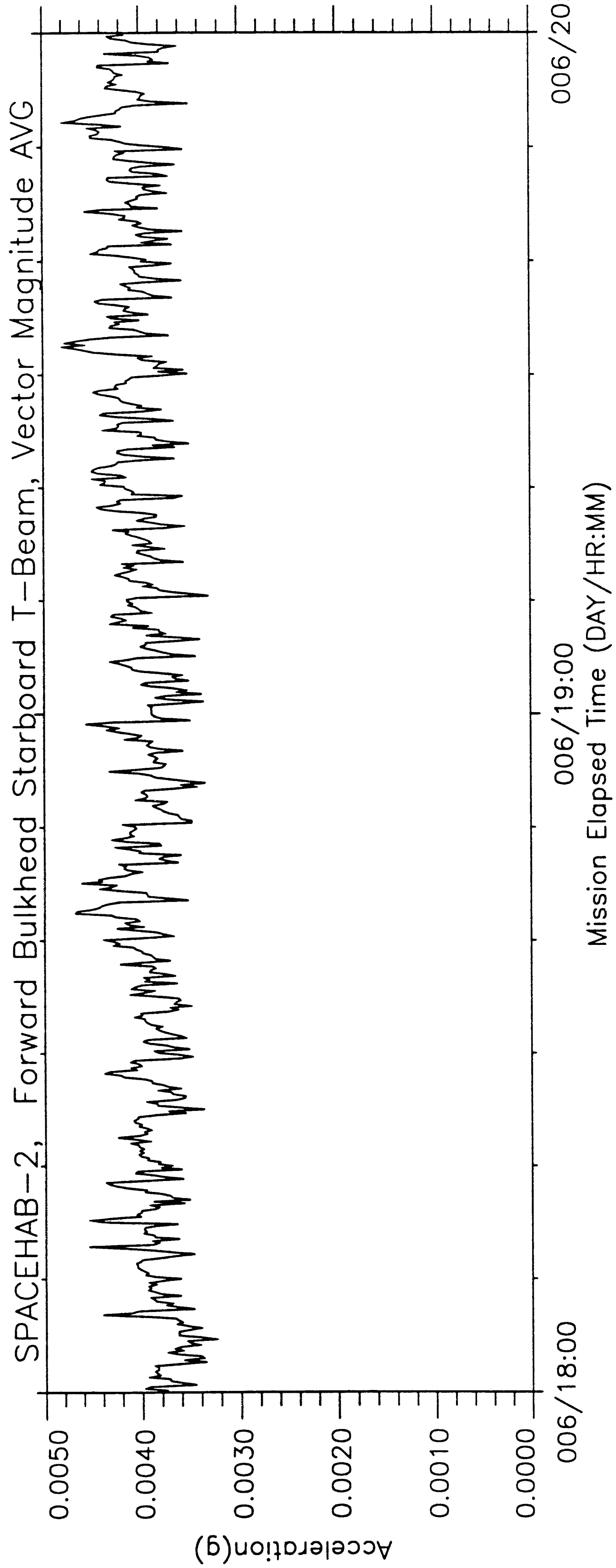
006/18:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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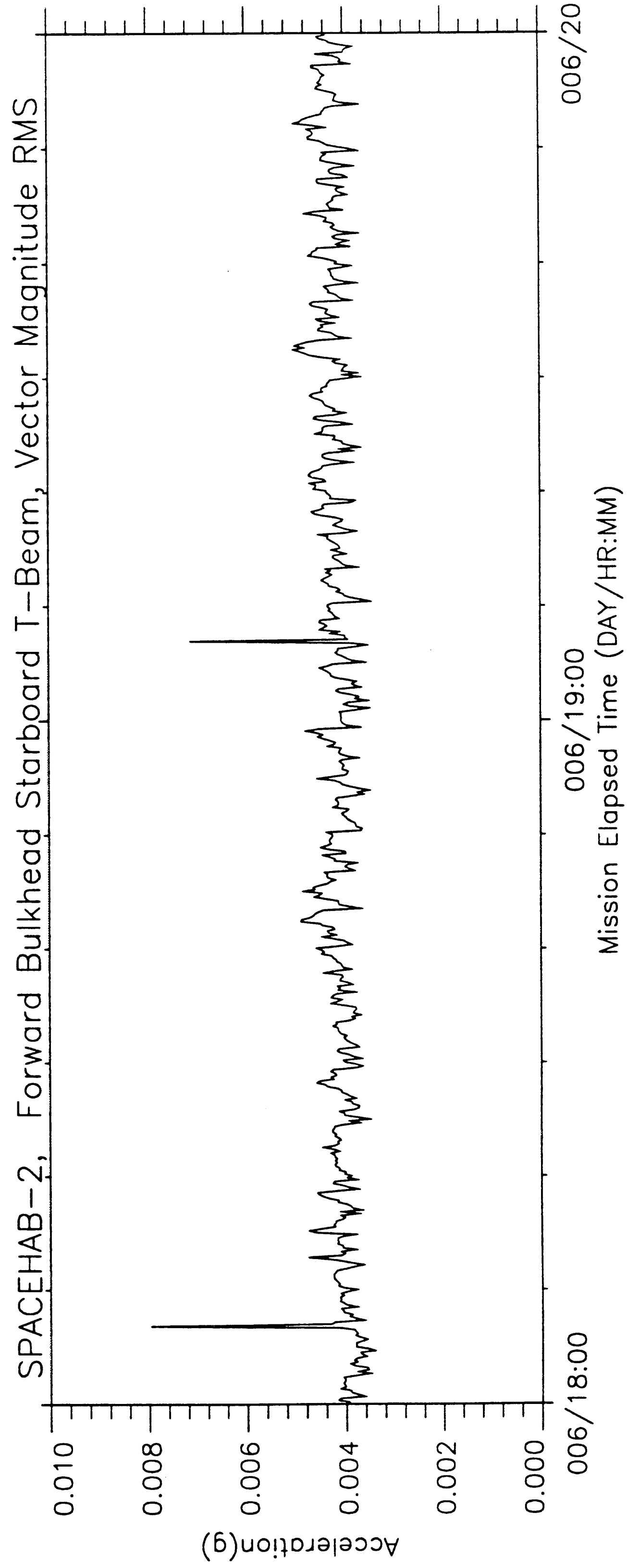
006/19:00
006/20:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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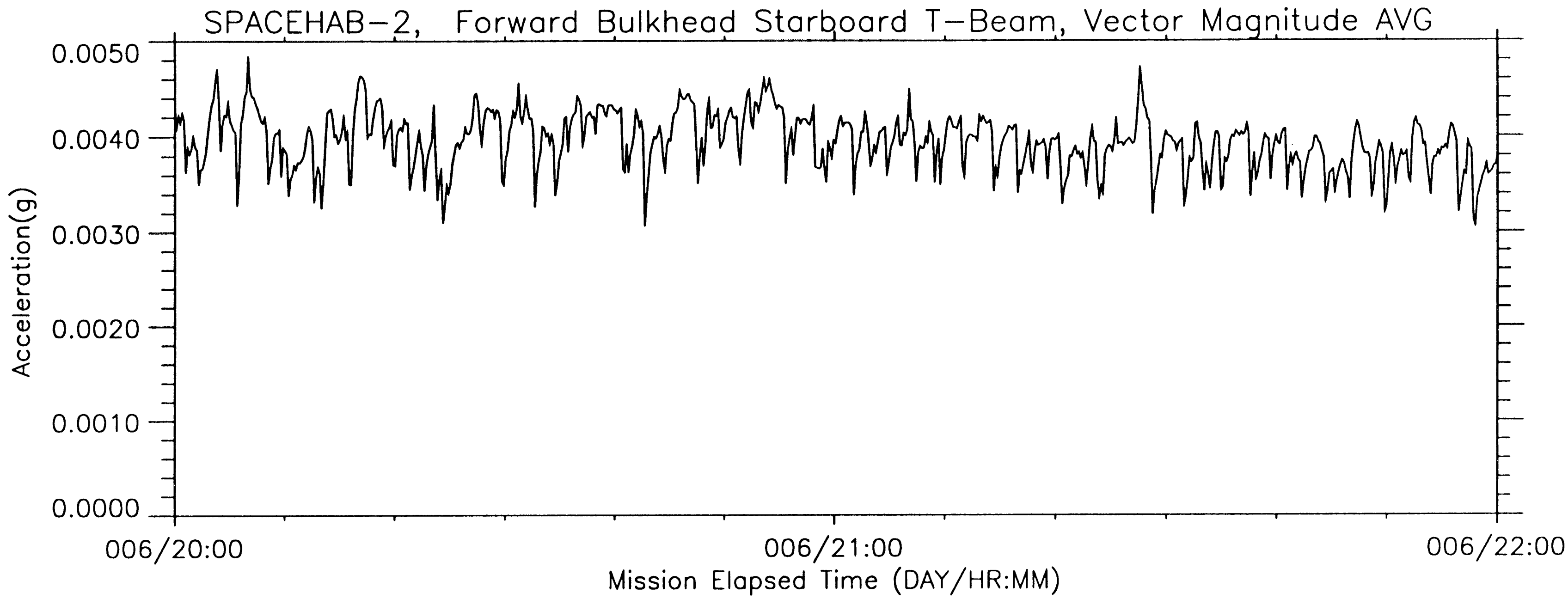
0.002
0.000
006/18:00
006/19:00
006/20:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
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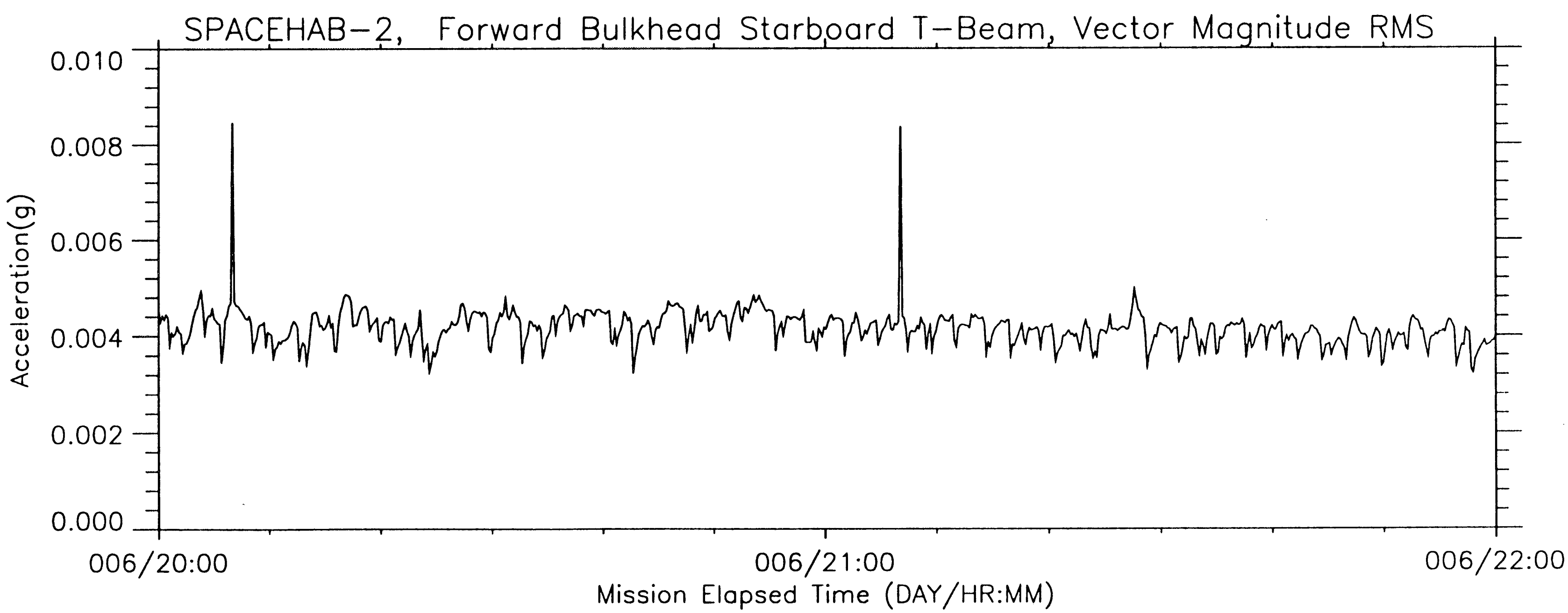
0.0000
Acceleration(g)
006/20:00
006/21:00
006/22:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
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0.008
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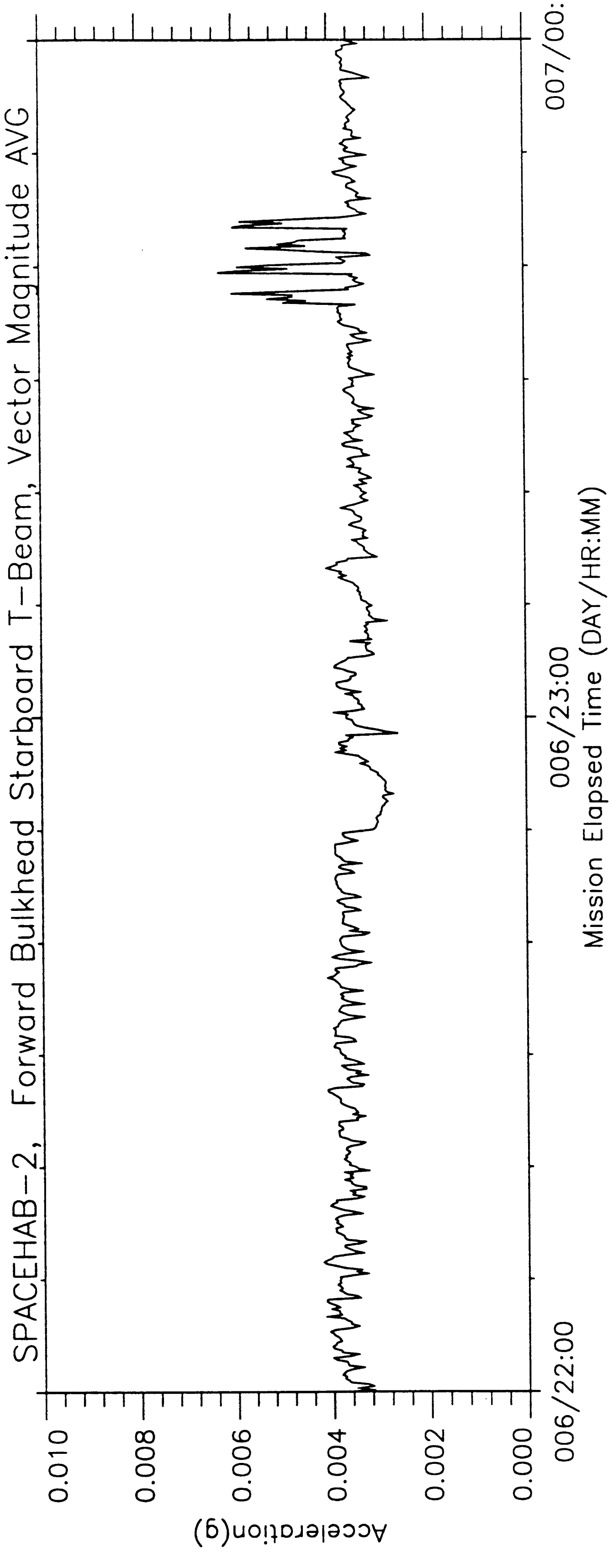
0.000
Acceleration(g)
006/20:00
006/21:00
006/22:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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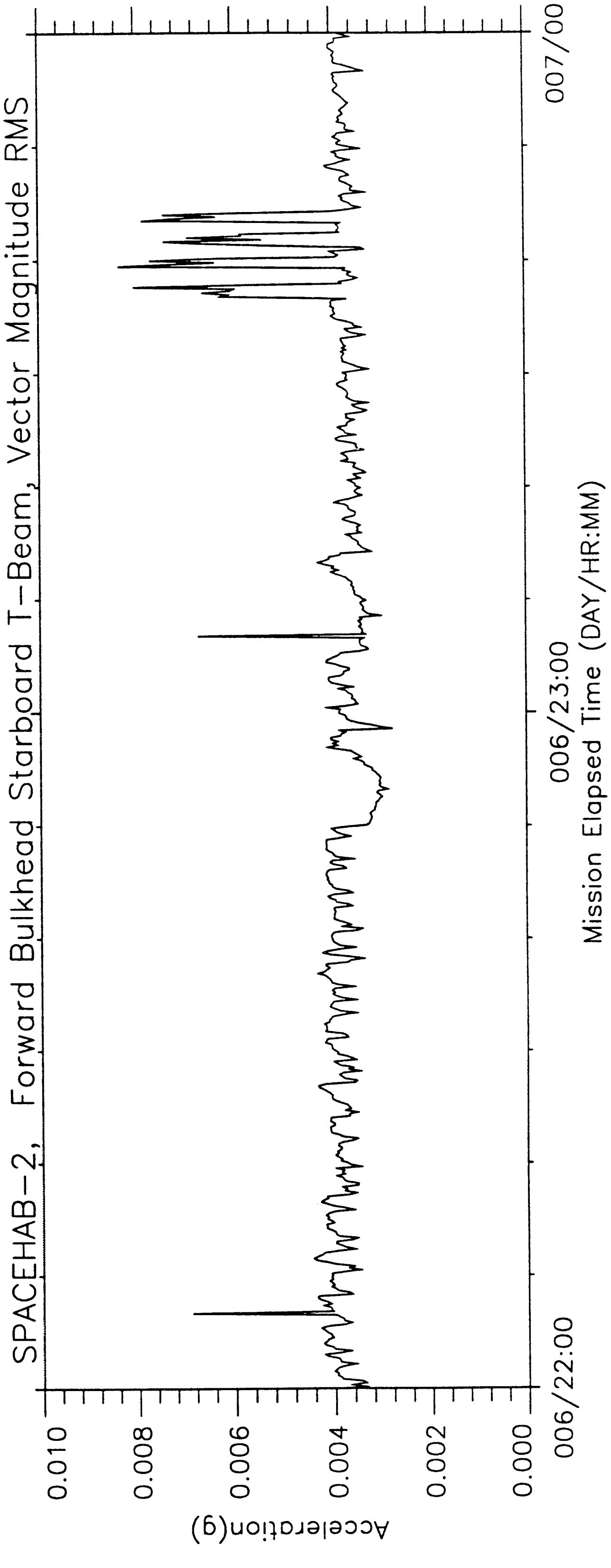
0.008
0.006
0.004
0.002
0.000
006/22:00
006/23:00
007/00:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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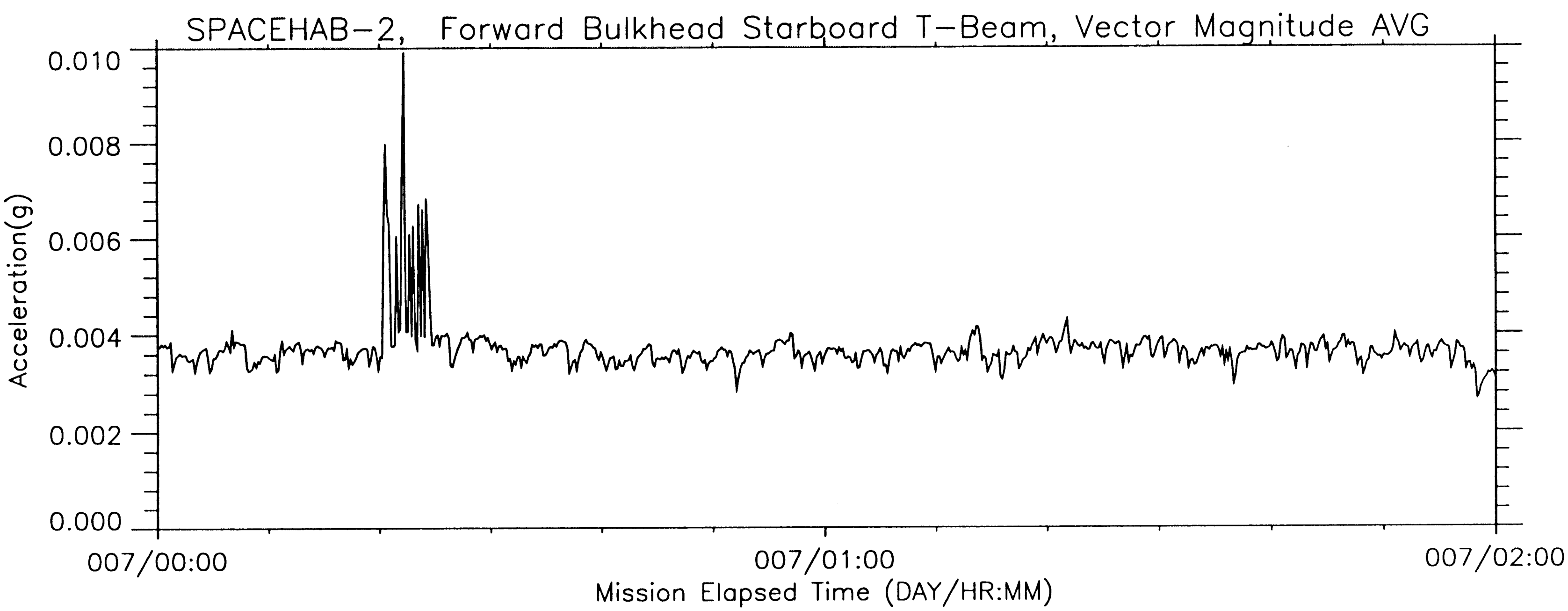
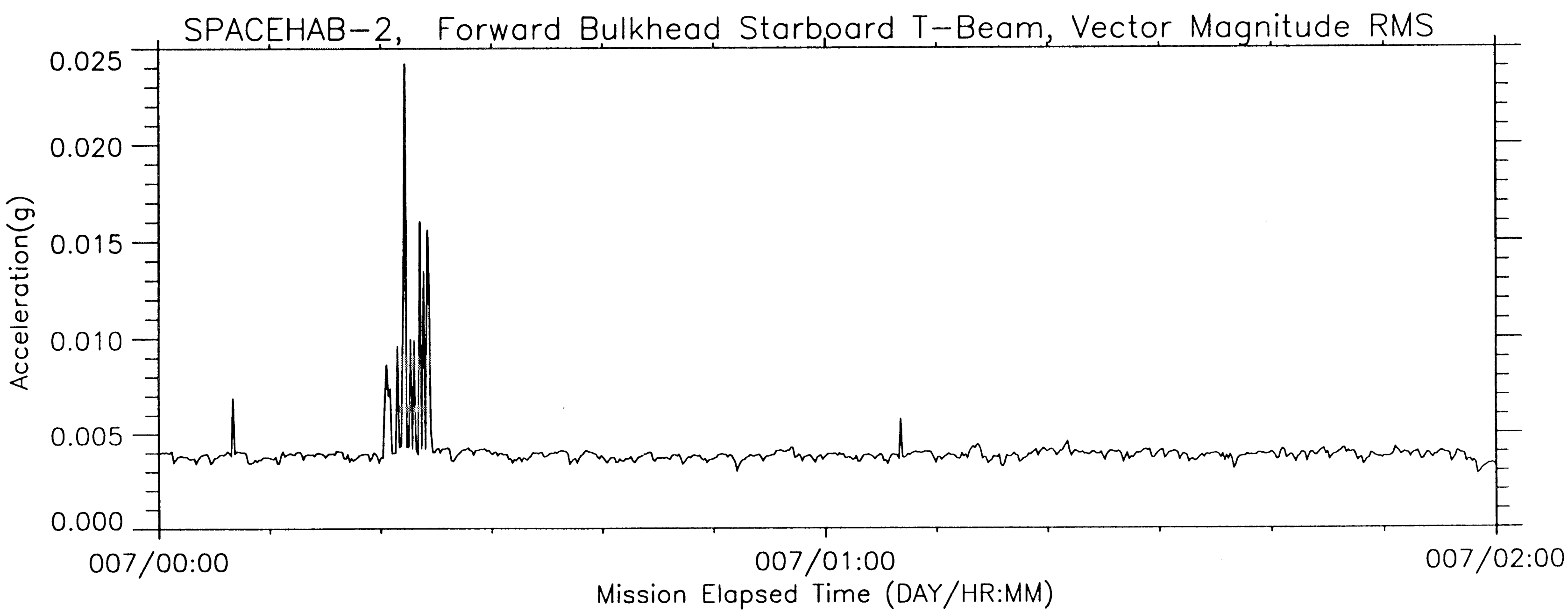
0.008
0.006
0.004
0.002
0.000
006/22:00
006/23:00
007/00:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
0.010
0.008
0.006
0.004
0.002
0.000
007/00:00
007/01:00
007/02:00
Mission Elapsed Time (DAY/HR:MM)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Acceleration(g)
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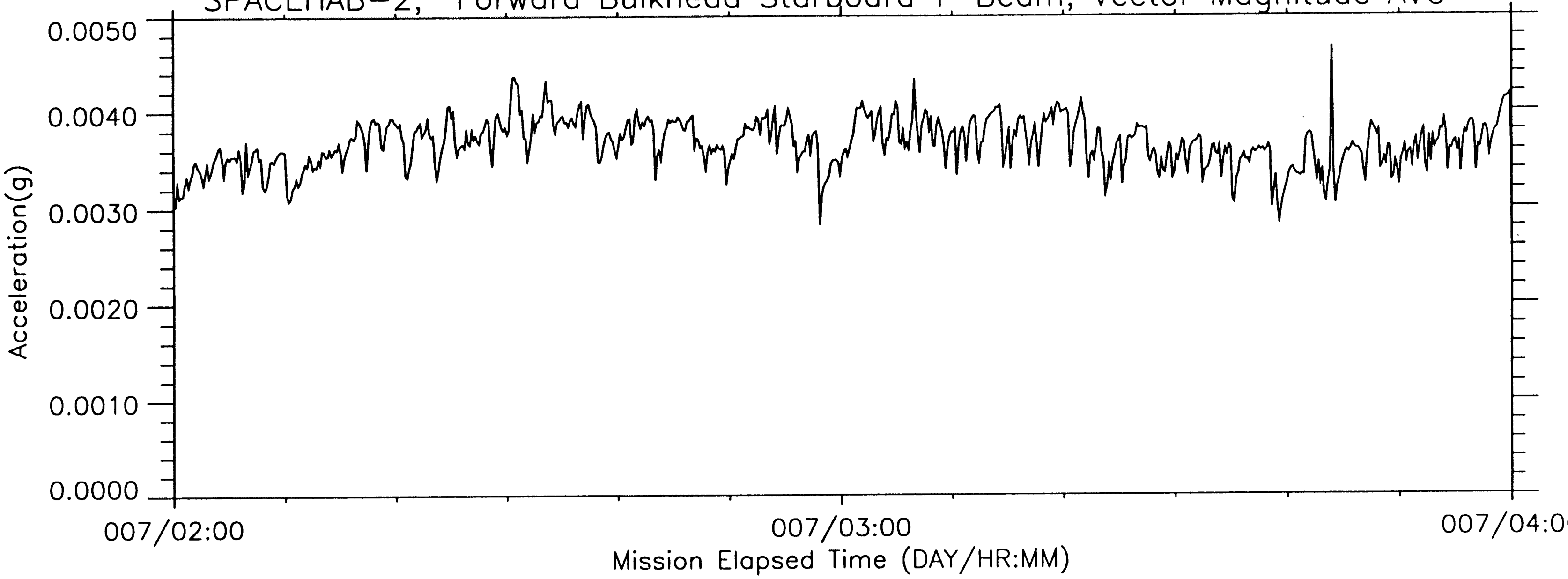
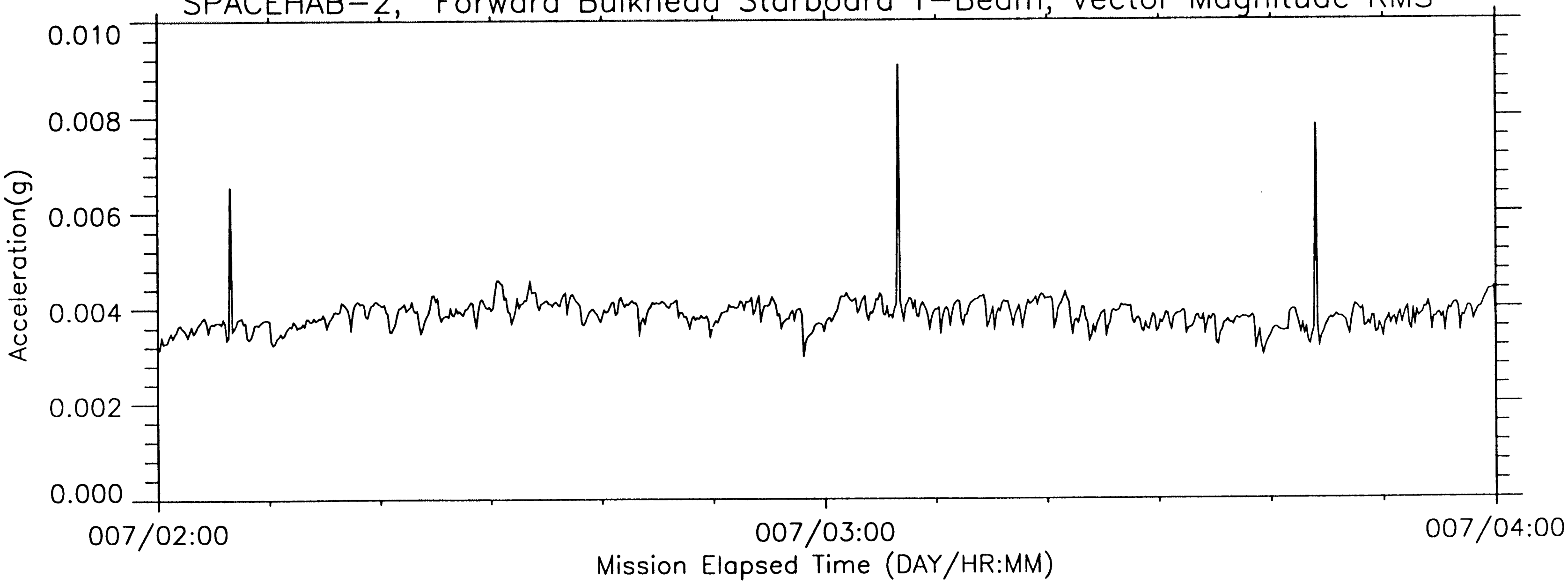
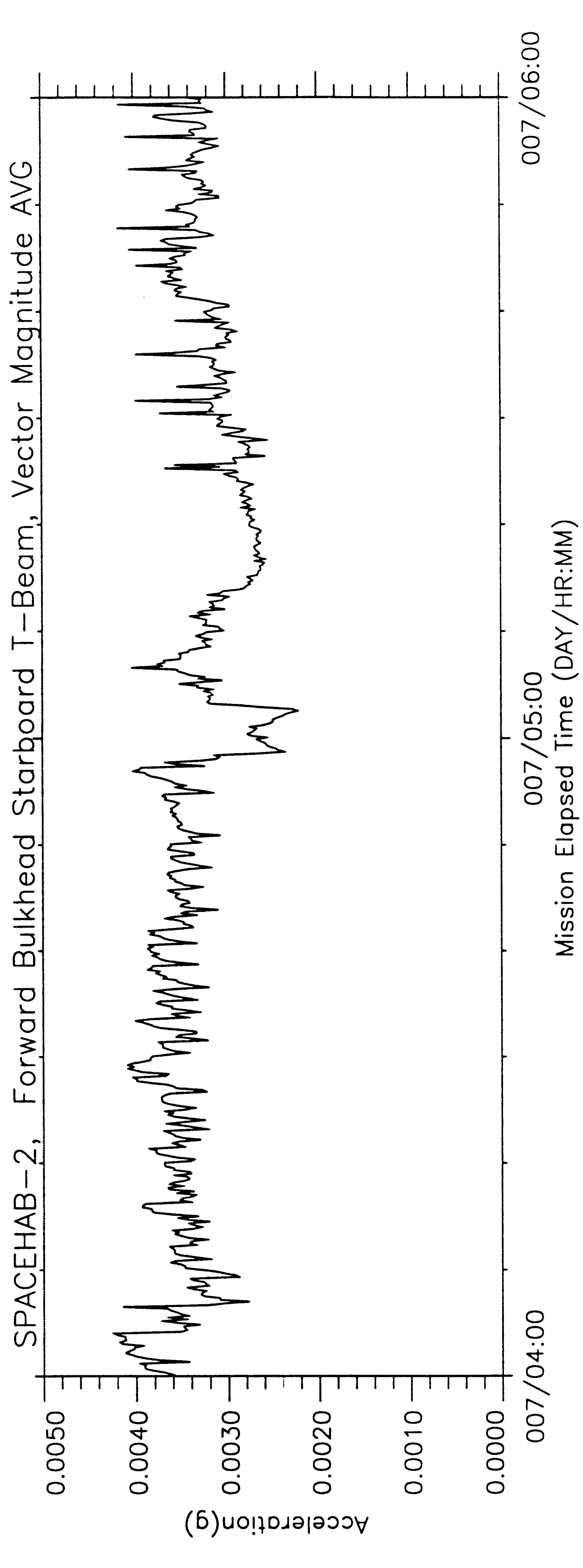
0.020
0.015
0.010
0.005
0.000
007/00:00
007/01:00
007/02:00
Mission Elapsed Time (DAY/HR:MM)

SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG



SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS




SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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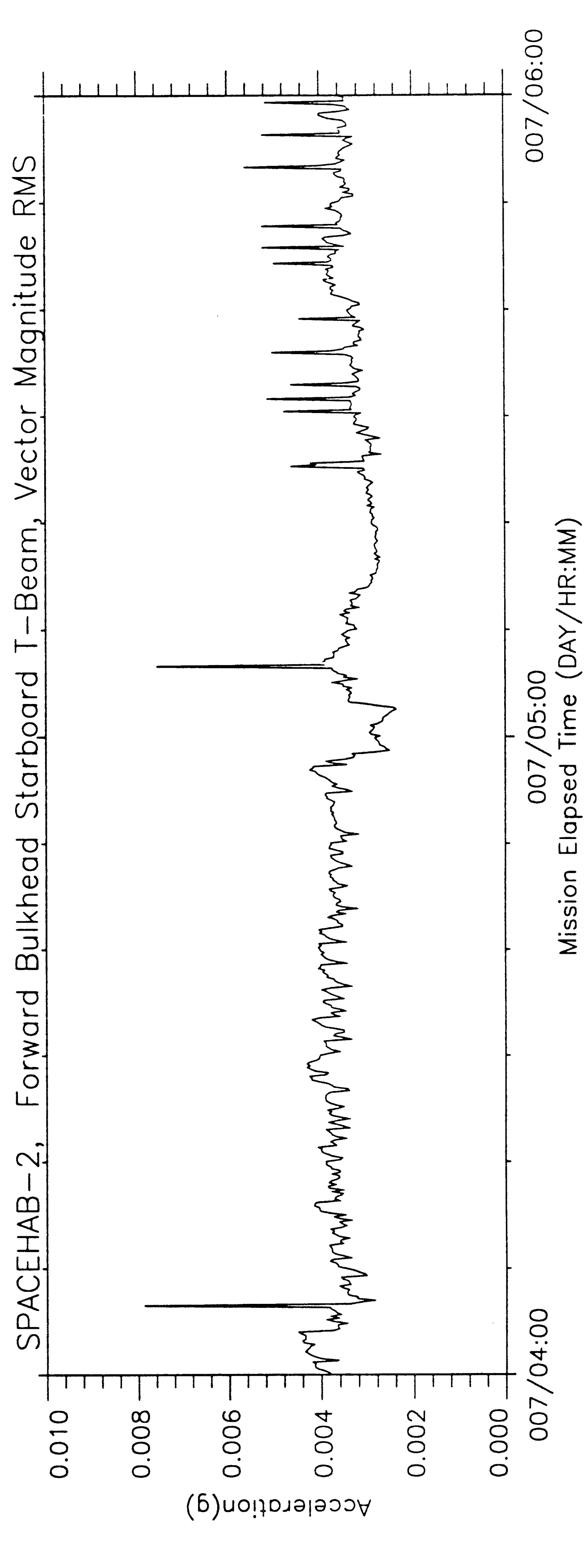
0.0030
0.0020
0.0010
0.0000
007/04:00
007/05:00
007/06:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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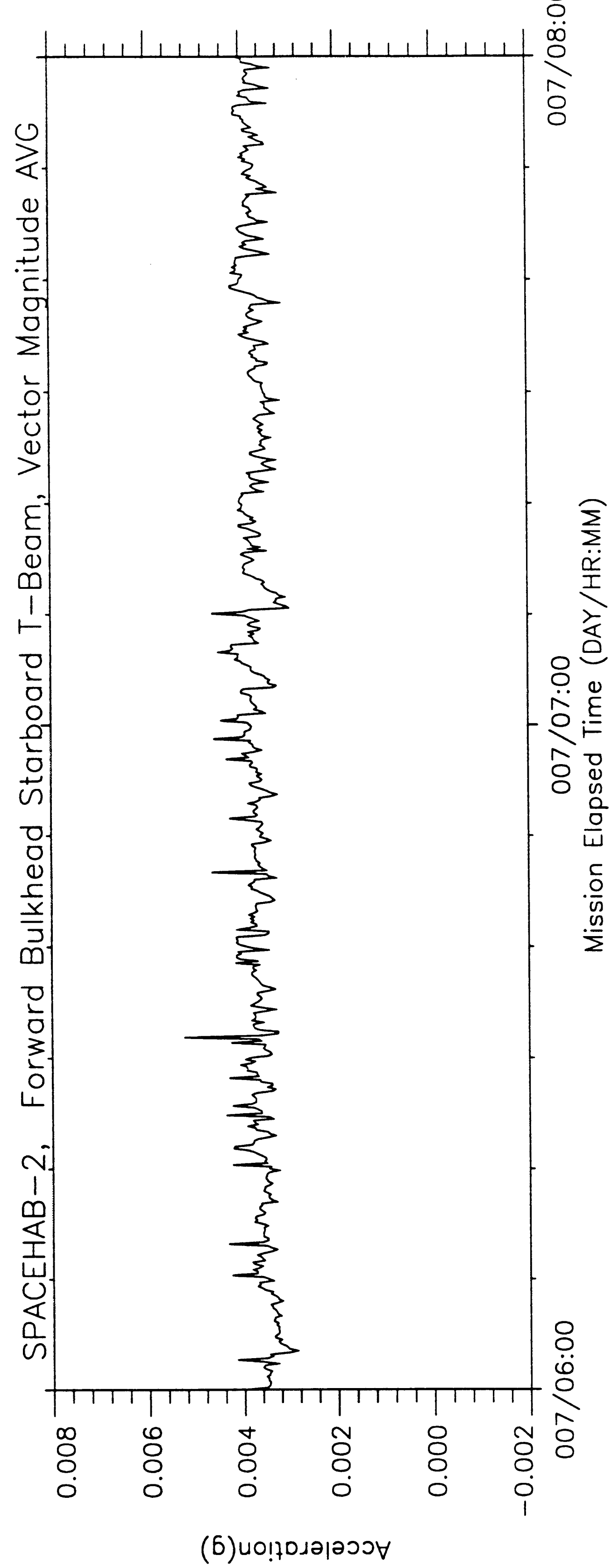
0.008
0.006
0.004
0.002
0.000
007/04:00
007/05:00
007/06:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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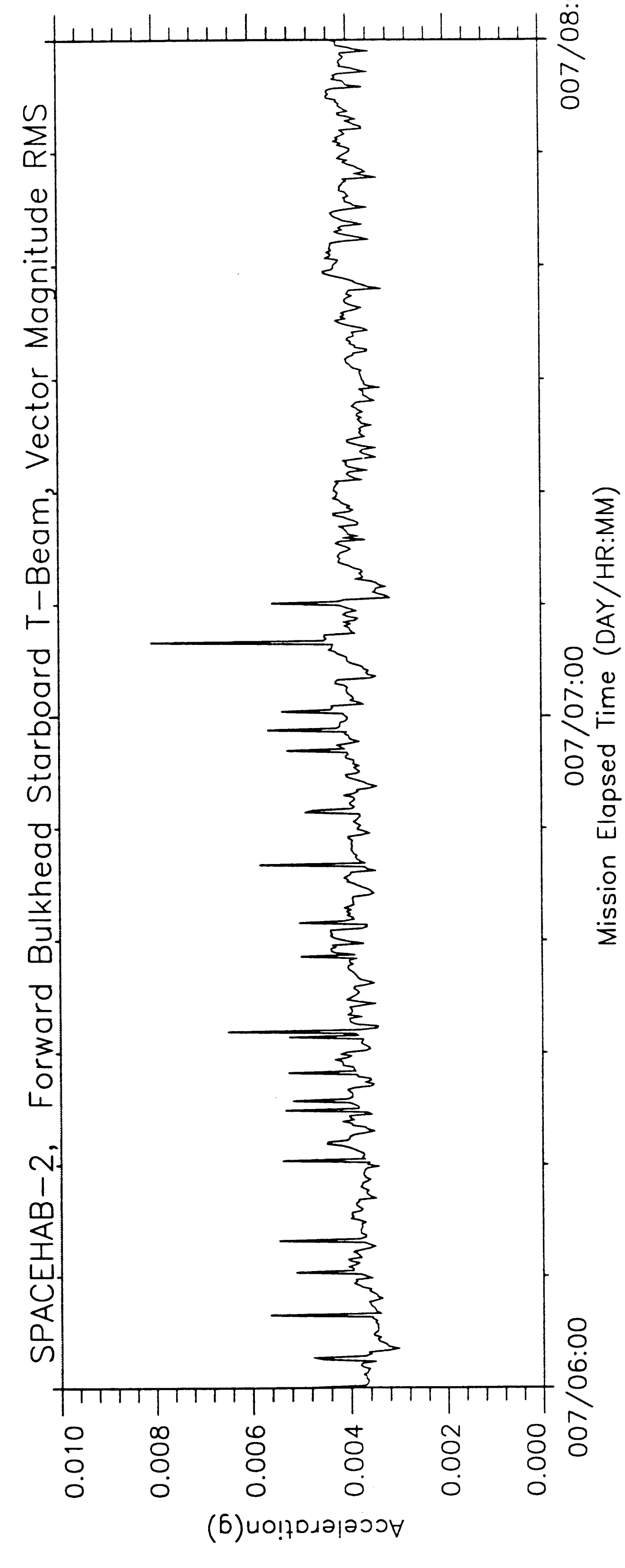
0.006
0.004
0.002
0.000
-0.002
007/06:00
007/07:00
007/08:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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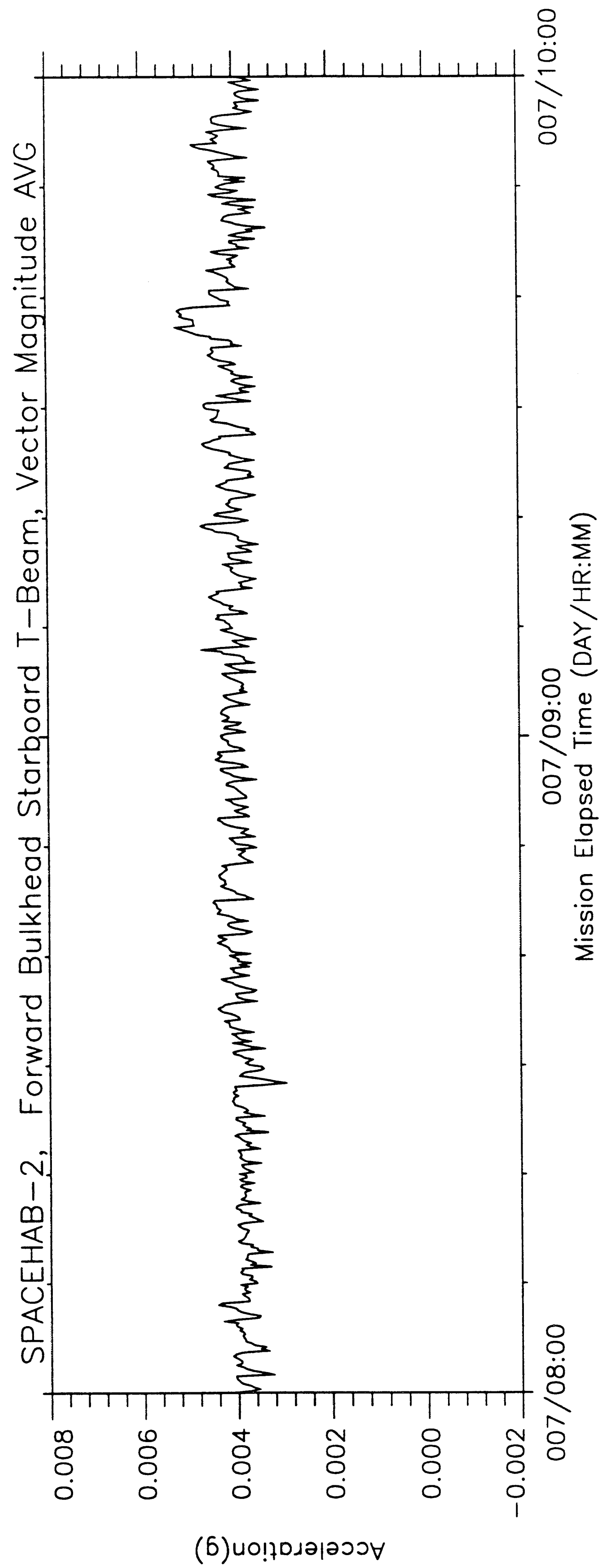
0.008
0.006
0.004
0.002
0.000
007/06:00
007/07:00
007/08:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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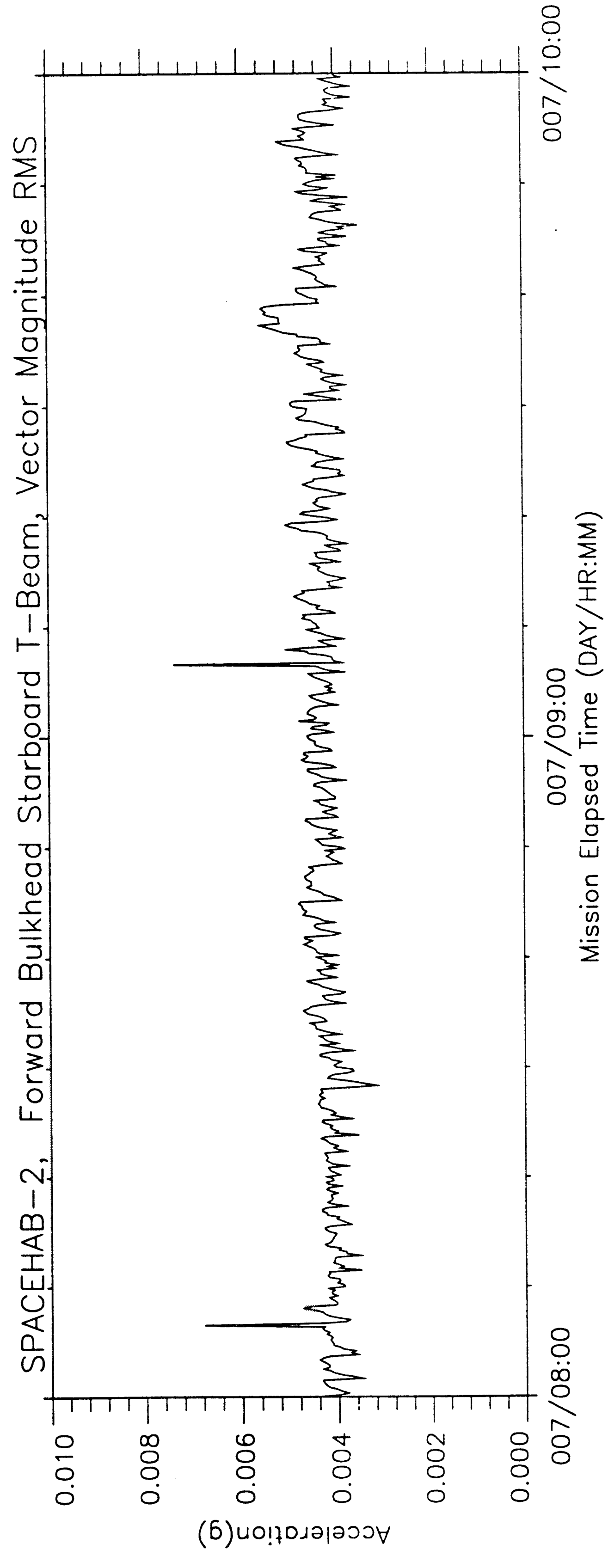
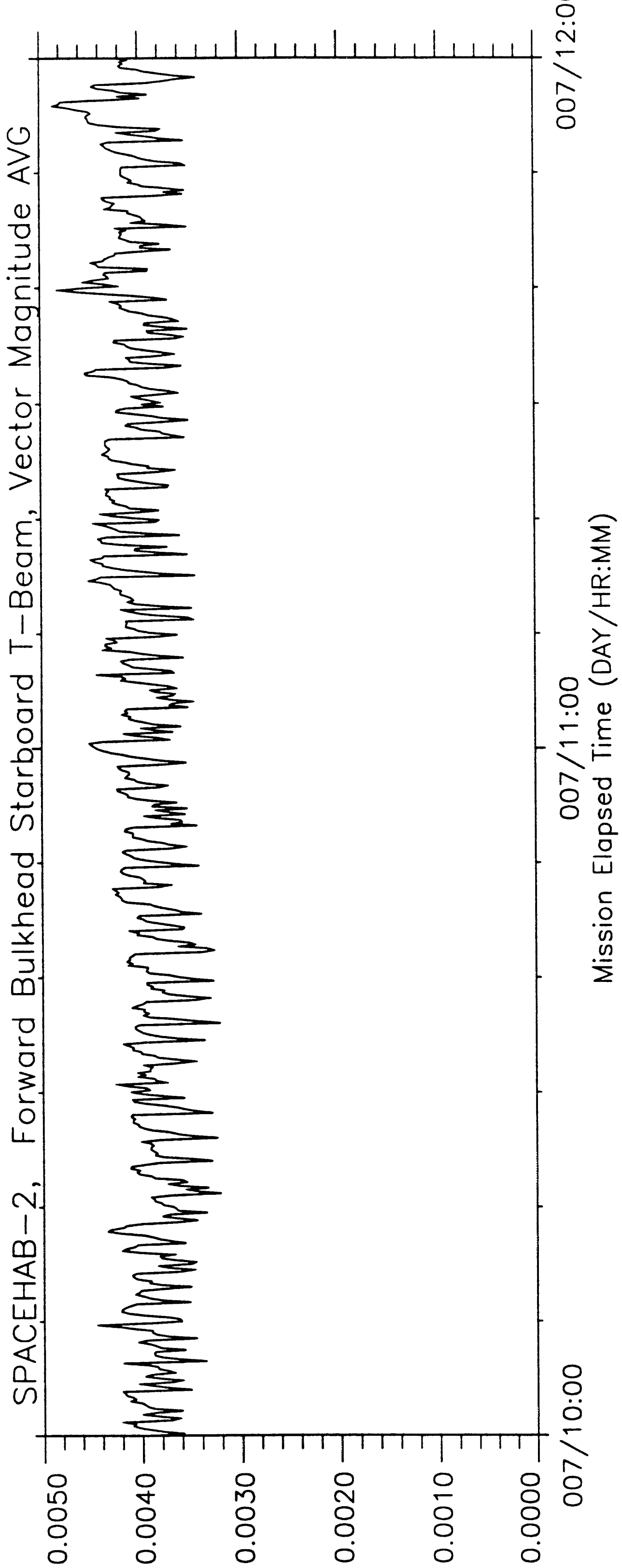
0.006
0.004
0.002
0.000
-0.002
007/08:00
007/09:00
007/10:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
0.010
0.008
0.006
0.004
0.002
0.000
007/08:00
007/09:00
007/10:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
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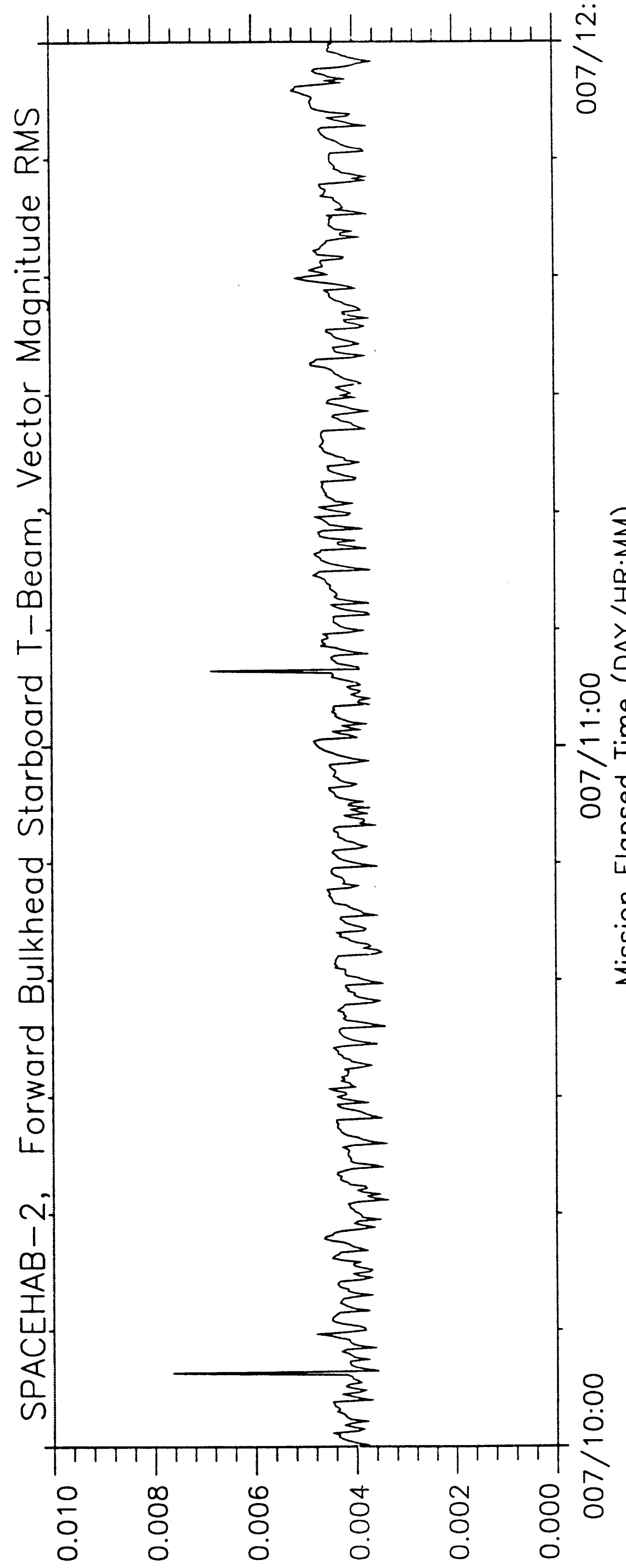
0.0040
0.0030
0.0020
0.0010
0.0000
007/10:00
007/11:00
007/12:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
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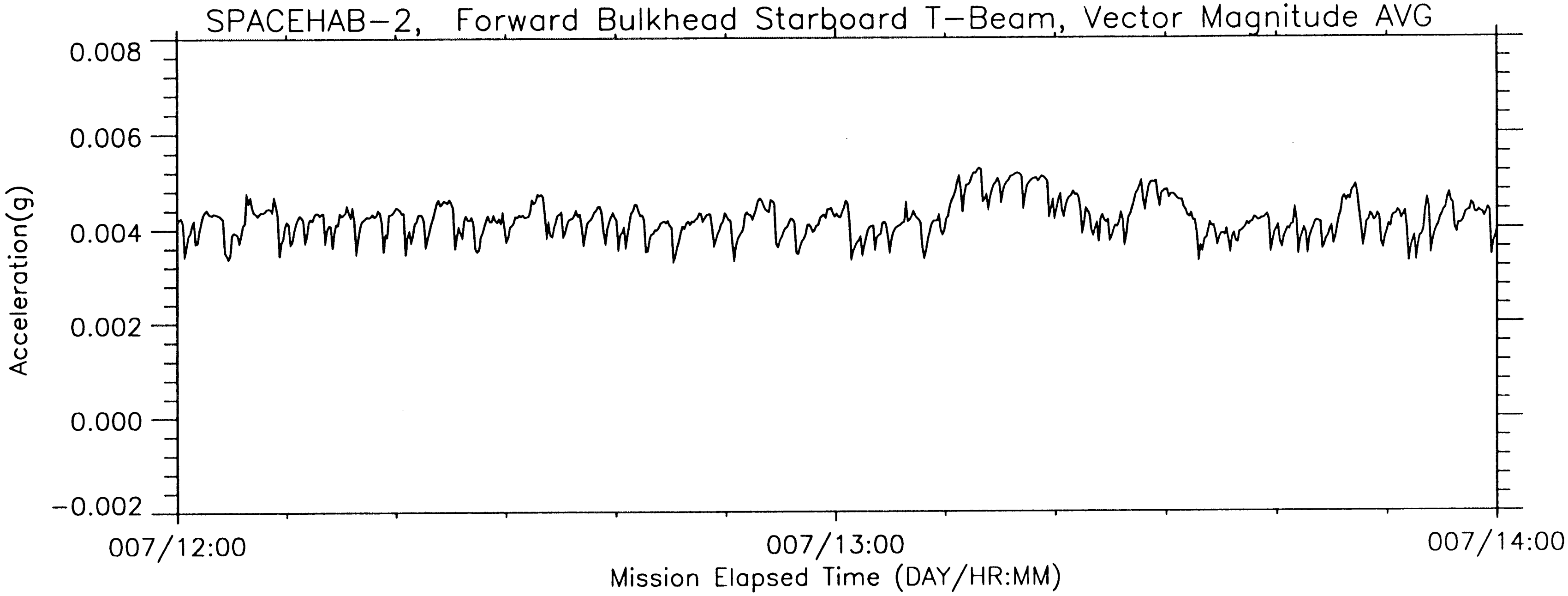
0.008
0.006
0.004
0.002
0.000
007/10:00
007/11:00
007/12:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
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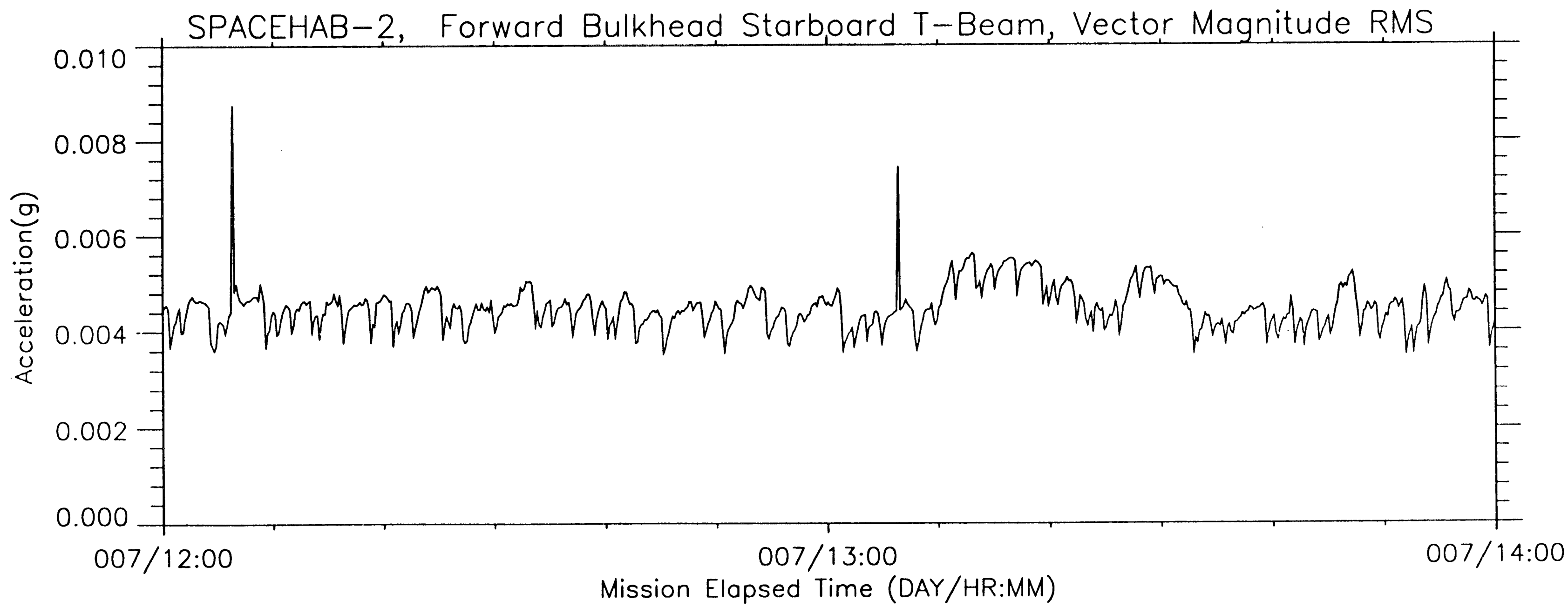
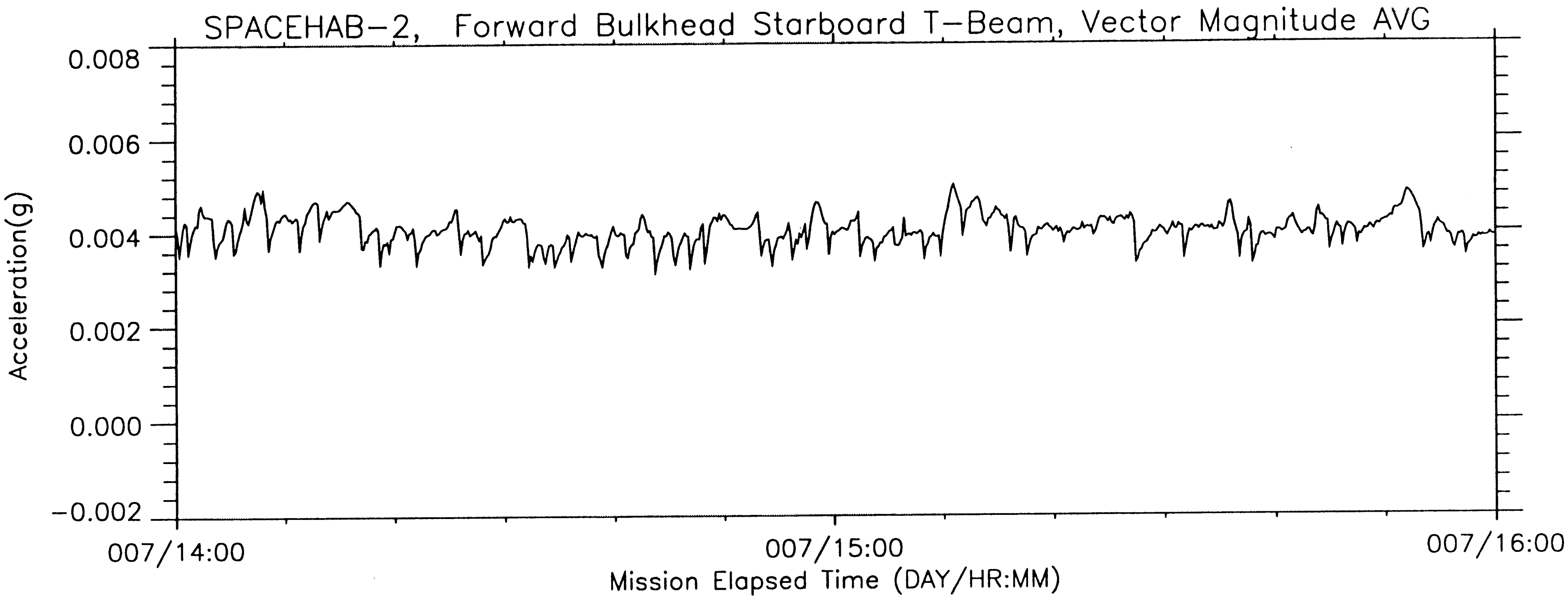
0.006
0.004
0.002
0.000
-0.002
Acceleration(g)
007/12:00
007/13:00
007/14:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
0.010
0.008
0.006
0.004
0.002
0.000
Acceleration(g)
007/12:00
007/13:00
007/14:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude AVG
Acceleration(g)
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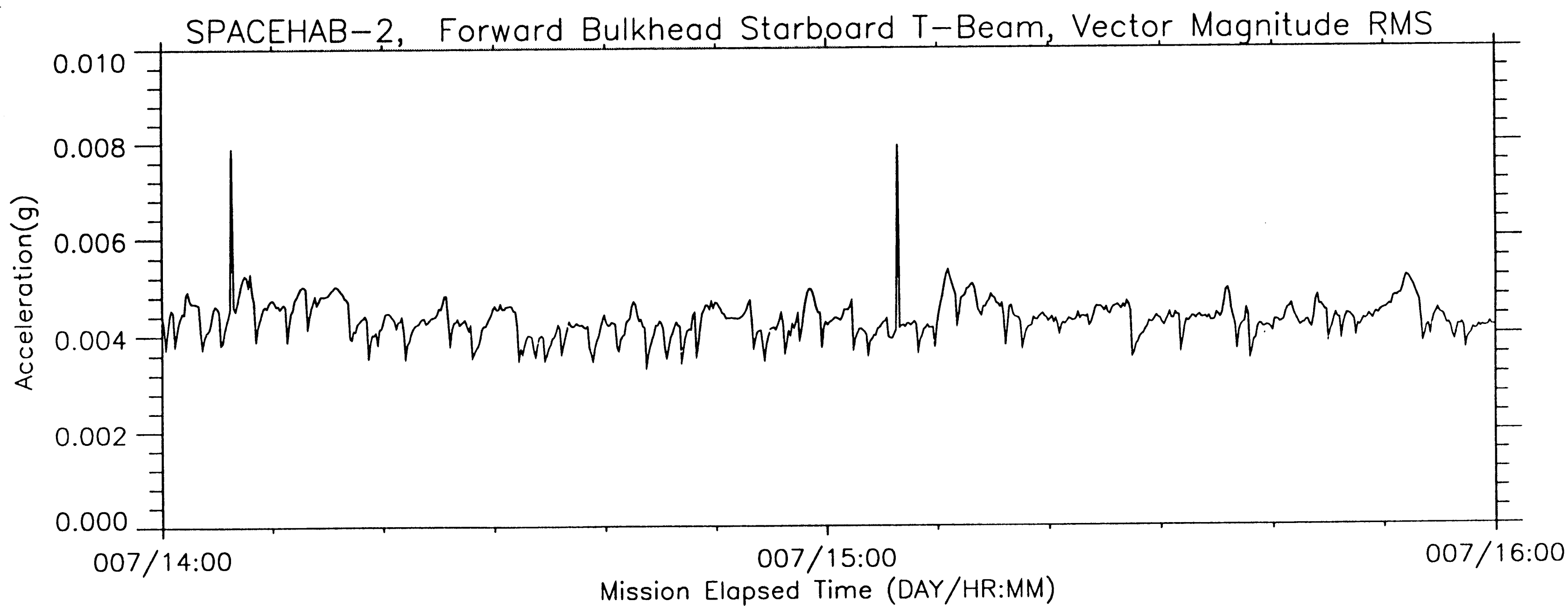
0.006
0.004
0.002
0.000
−0.002
007/14:00
007/15:00
007/16:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB−2, Forward Bulkhead Starboard T−Beam, Vector Magnitude RMS
Acceleration(g)
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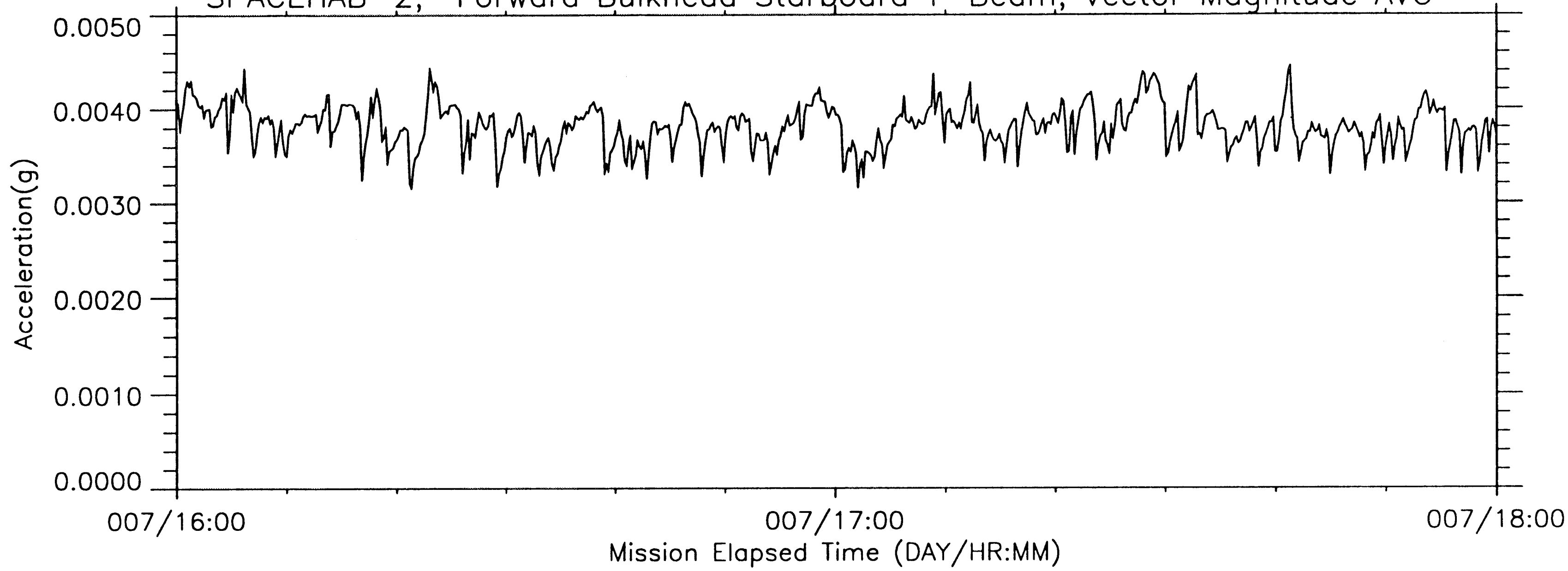
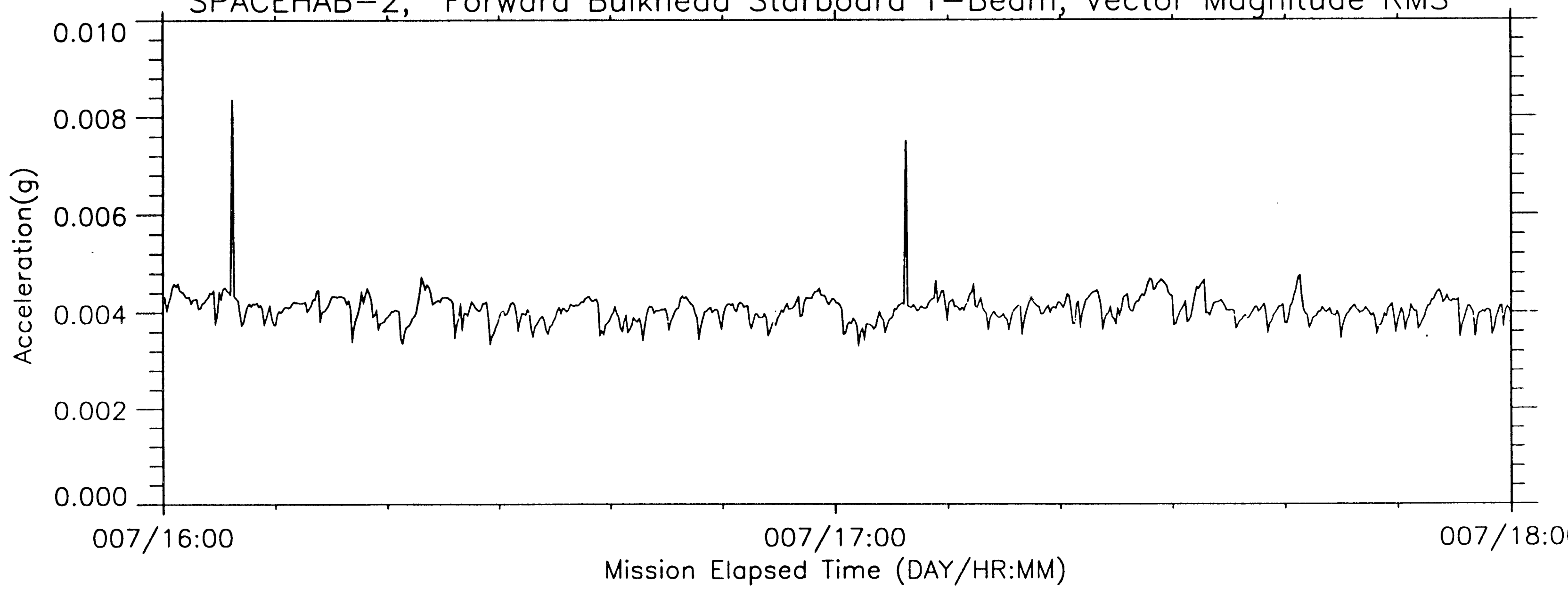
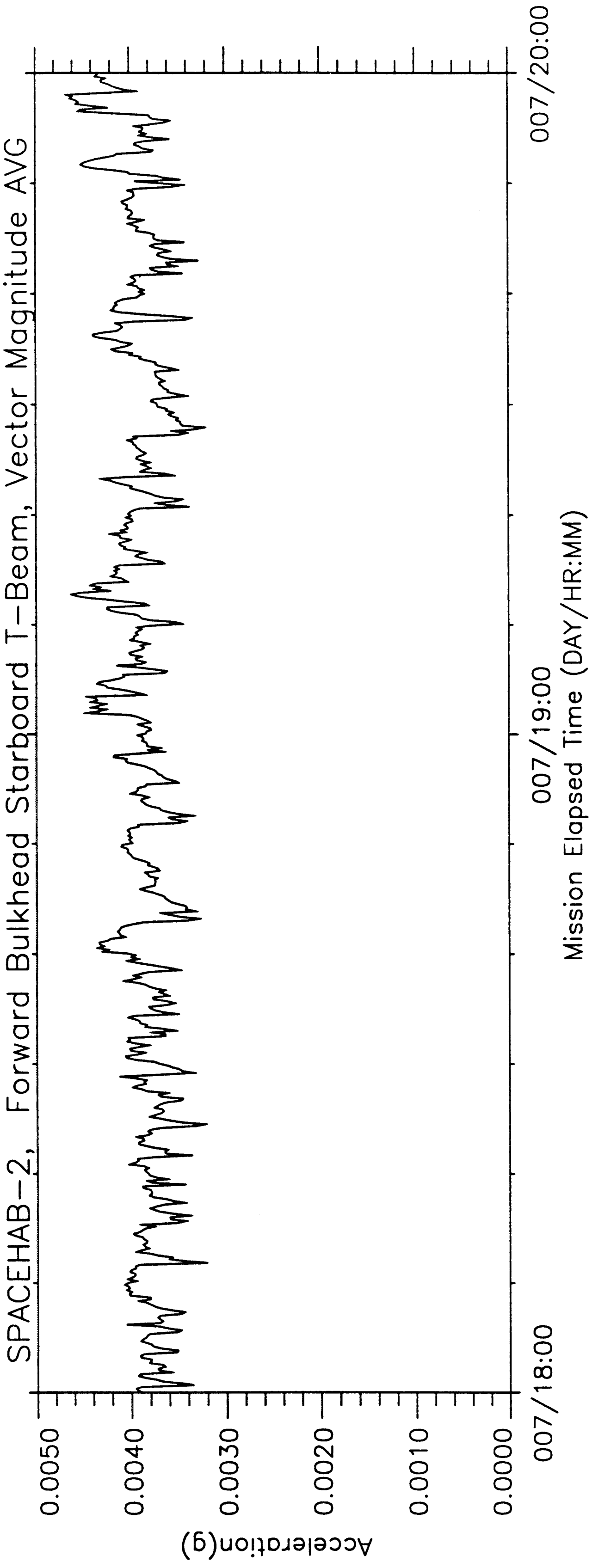
0.008
0.006
0.004
0.002
0.000
007/14:00
007/15:00
007/16:00
Mission Elapsed Time (DAY/HR:MM)

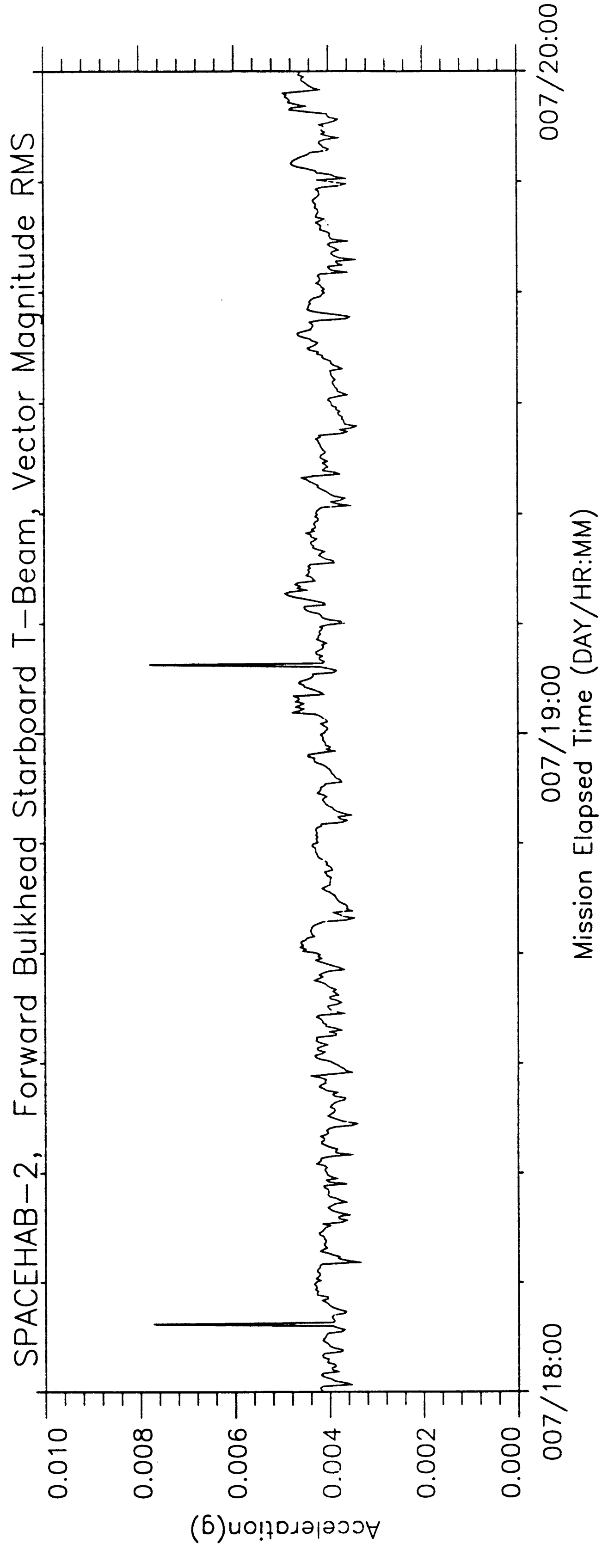
SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG

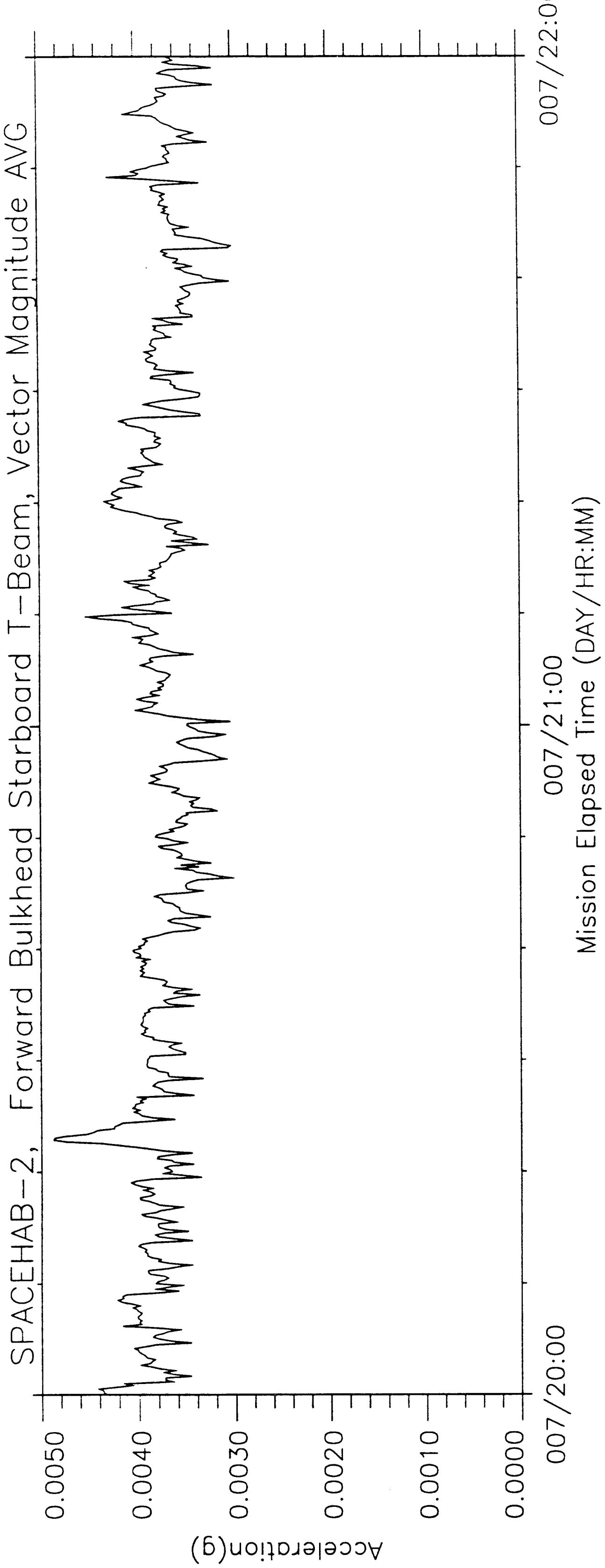


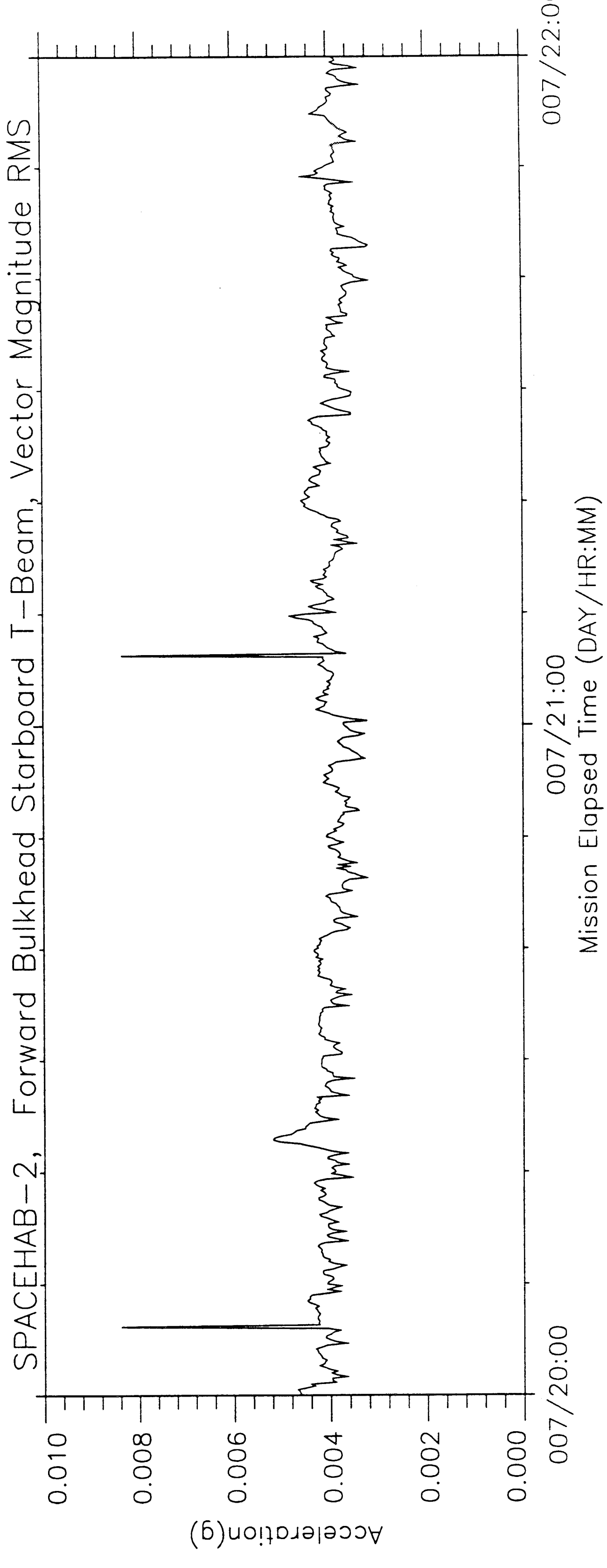
SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS




SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
007/18:00
007/19:00
007/20:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
0.010
0.008
0.006
0.004
0.002
0.000
007/18:00
007/19:00
007/20:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude AVG
Acceleration(g)
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
007/20:00
007/21:00
007/22:00
Mission Elapsed Time (DAY/HR:MM)


SPACEHAB-2, Forward Bulkhead Starboard T-Beam, Vector Magnitude RMS
Acceleration(g)
0.010
0.008
0.006
0.004
0.002
0.000
007/20:00
007/21:00
007/22:00
Mission Elapsed Time (DAY/HR:MM)

APPENDIX C SAMS COLOR SPECTROGRAMS

Accelerometer data collected on Orbiter missions are generally analyzed by the PI or experiment team responsible for the system. For this reason, the contact person listed in the body of this report should be contacted with any specific questions about accelerometers and mission data. The PI Microgravity Services (PIMS) project at the NASA Lewis Research Center was formed in part to support microgravity PIs in the evaluation of acceleration effects on their experiments and to characterize the vibrational environment of the Space Shuttle Orbiters. The primary continual source of accelerometer data from mission to mission is SAMS. Some of the SAMS data from STS-60 are presented in Appendices B and C to provide PIs with an overview of the environment during mission.

The raw data recorded by SAMS are processed to compensate for temperature and gain related errors of bias, scale factor, and axis misalignment. The processing utilizes a fourth order temperature model to compensate the data and convert the raw digitized data into engineering units [C1]. The data are transformed to the shuttle structural coordinate system and formatted into files for distribution via CD-ROM and file server. See Appendix A for information on file server access of SAMS data.

The SAMS data have been further processed to produce the plots shown here. Color spectrograms are provided as an overview of the frequency characteristics of the SAMS data during the mission. Each spectrogram is a two-hour composite of amplitude spectra for consecutive ten second intervals. These plots should be used to identify times when the frequency character of the acceleration environment changes.

The color spectrograms were produced using STS-60 SAMS Head B data. The data are presented in two hour periods where an amplitude spectrum was calculated for each consecutive ten second interval.

The spectral data were scaled by taking the log of each data point and assigning a color to the integer result. Eight colors were used for eight intervals between 1×10^{-7} g and 1×10^{-3} g. In using this method, a range of acceleration values are assigned to the same color.

References

[C1] Thomas, J. E., R. B. Peters, B. D. , Finley, B. D. , Space Acceleration Measurement System triaxial head error budget, NASA TM-105300, January 1992.

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Figure C-1 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

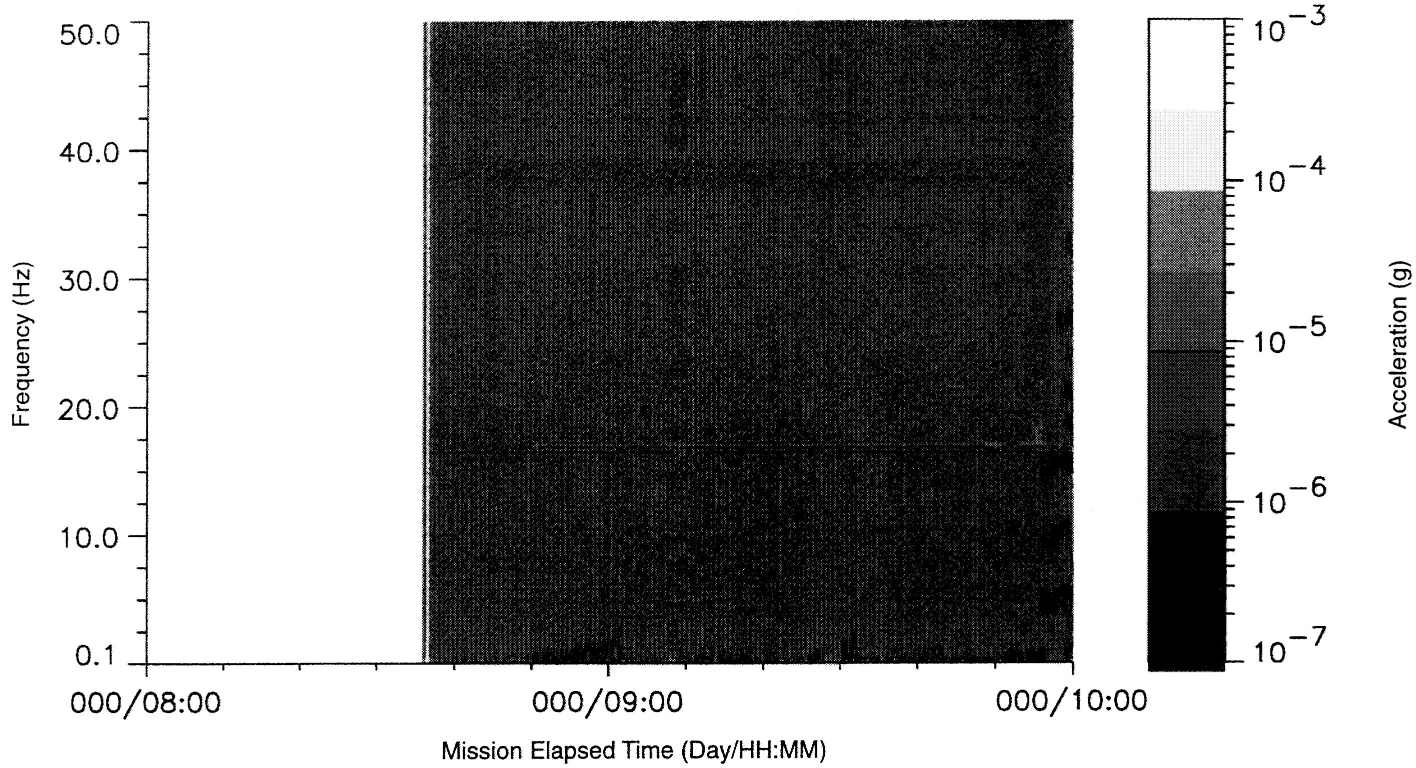

Figure C-2 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

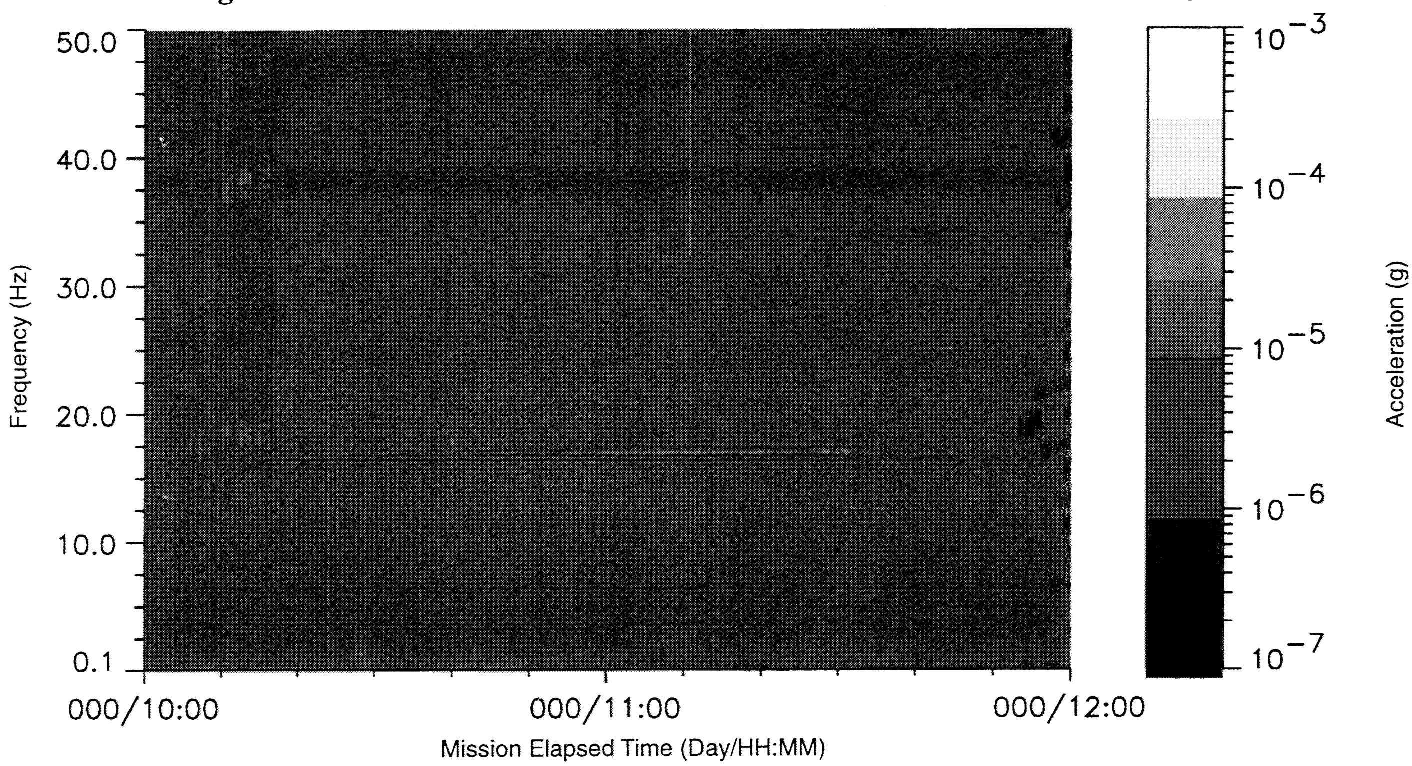

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Figure C-3 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

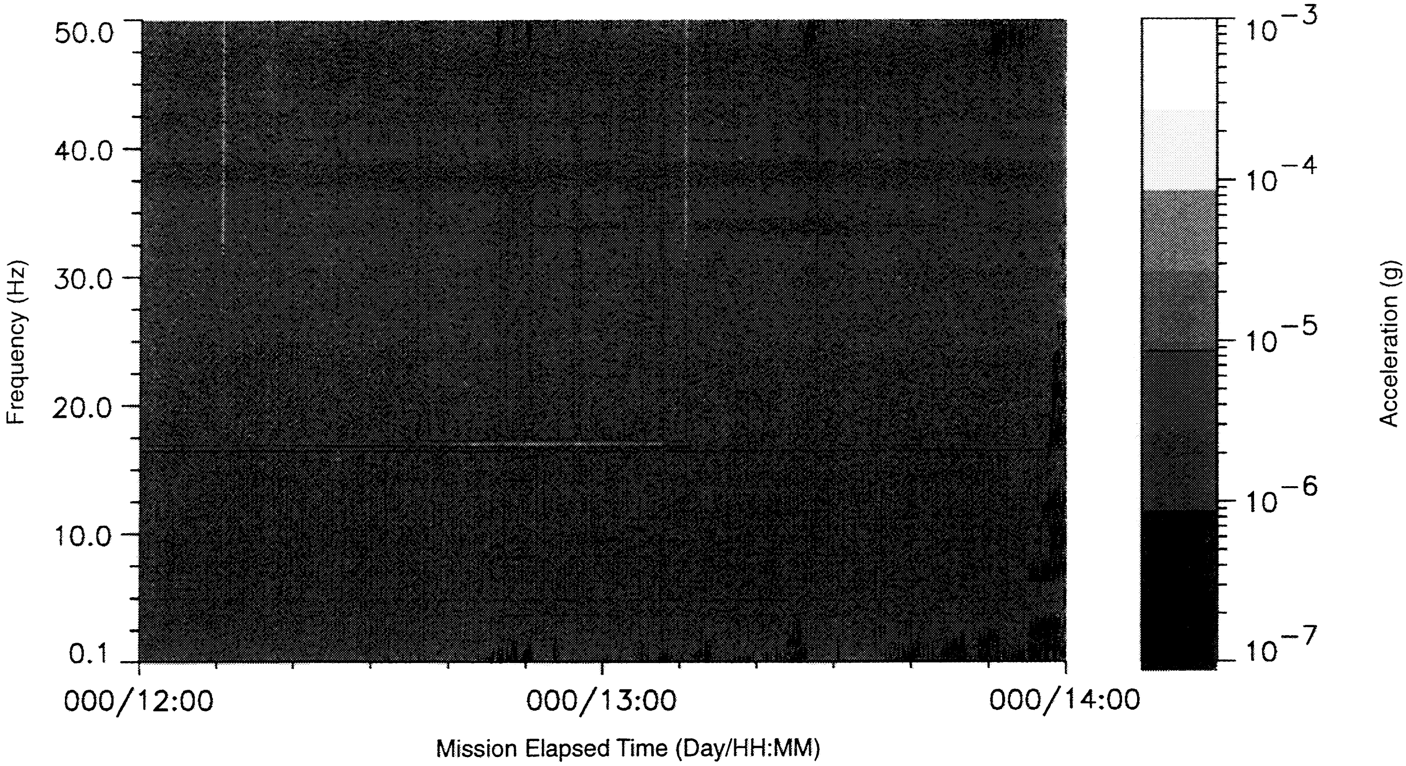

Figure C-4 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

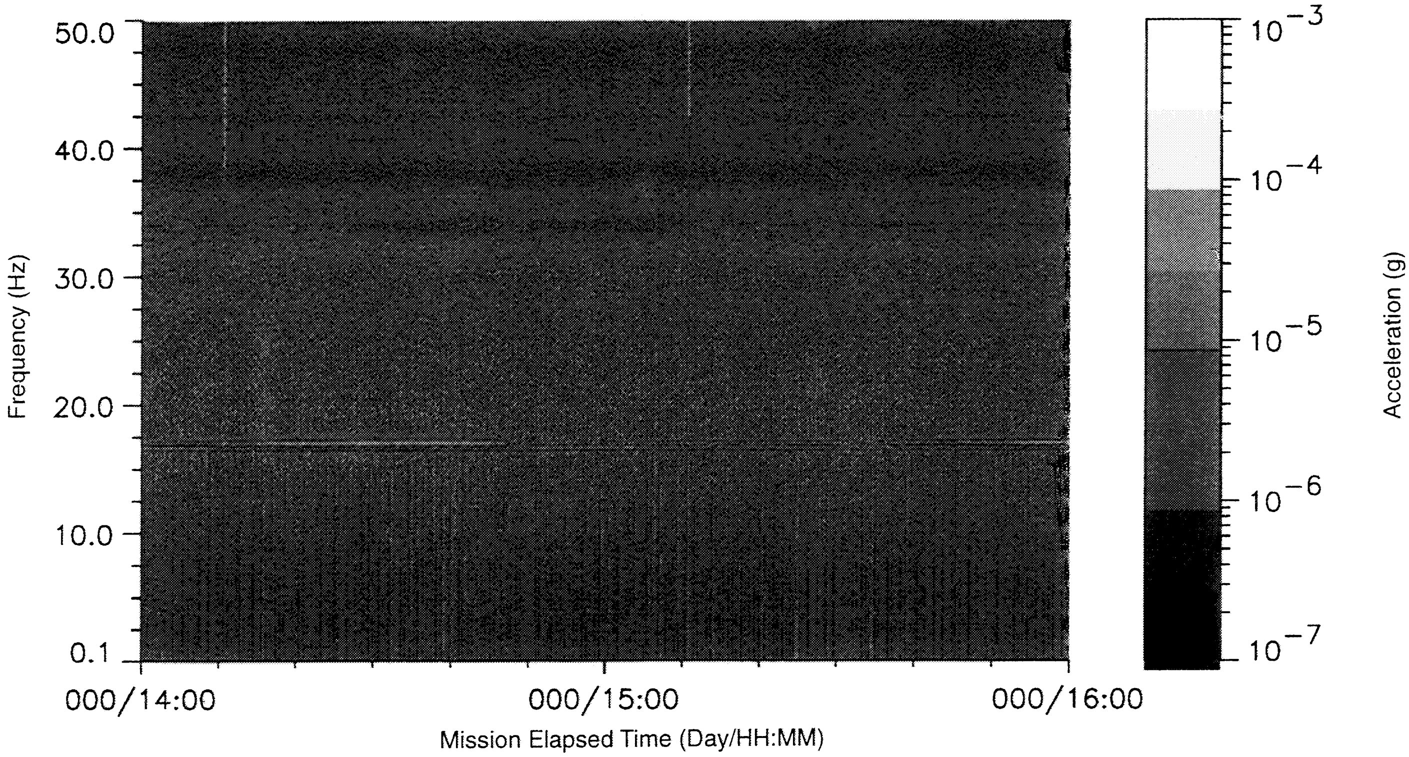

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Figure C-5 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

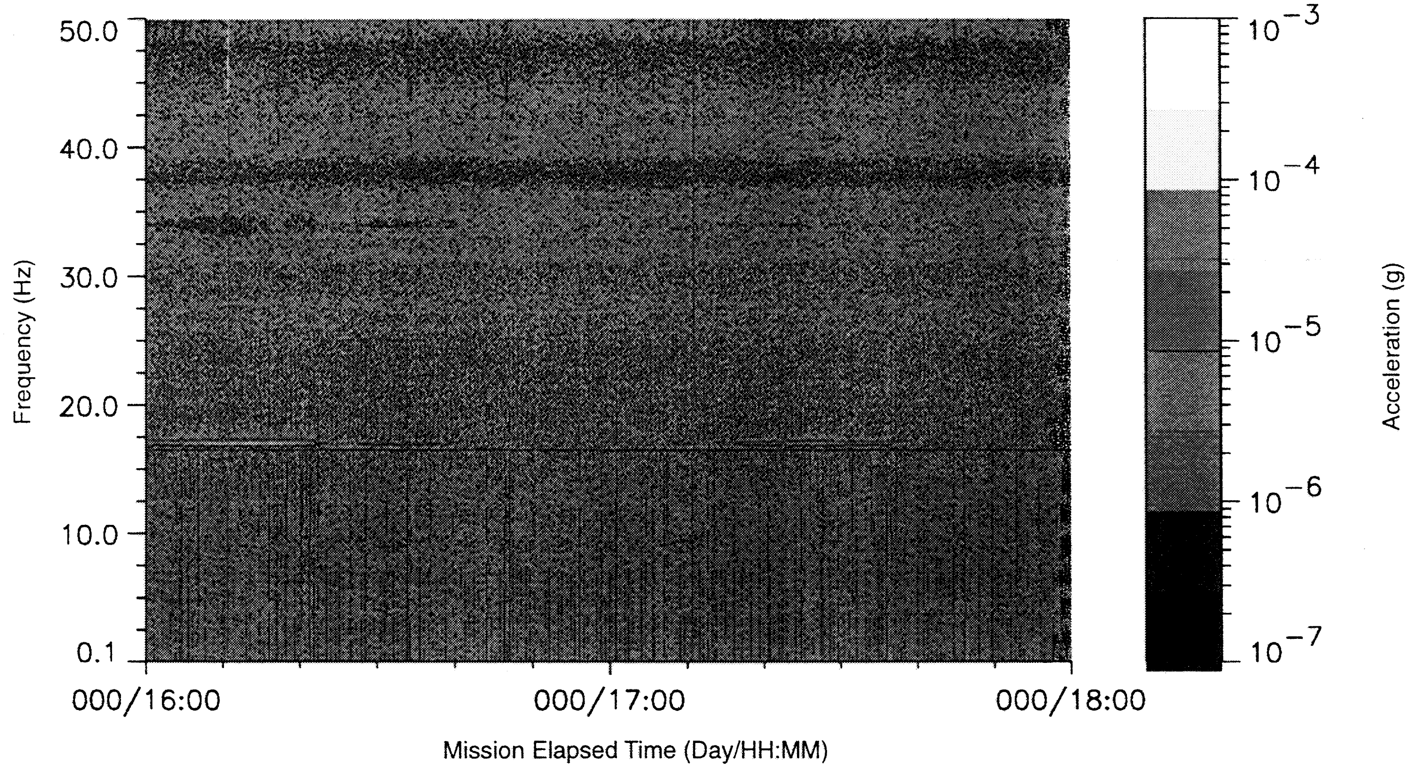

Figure C-6 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

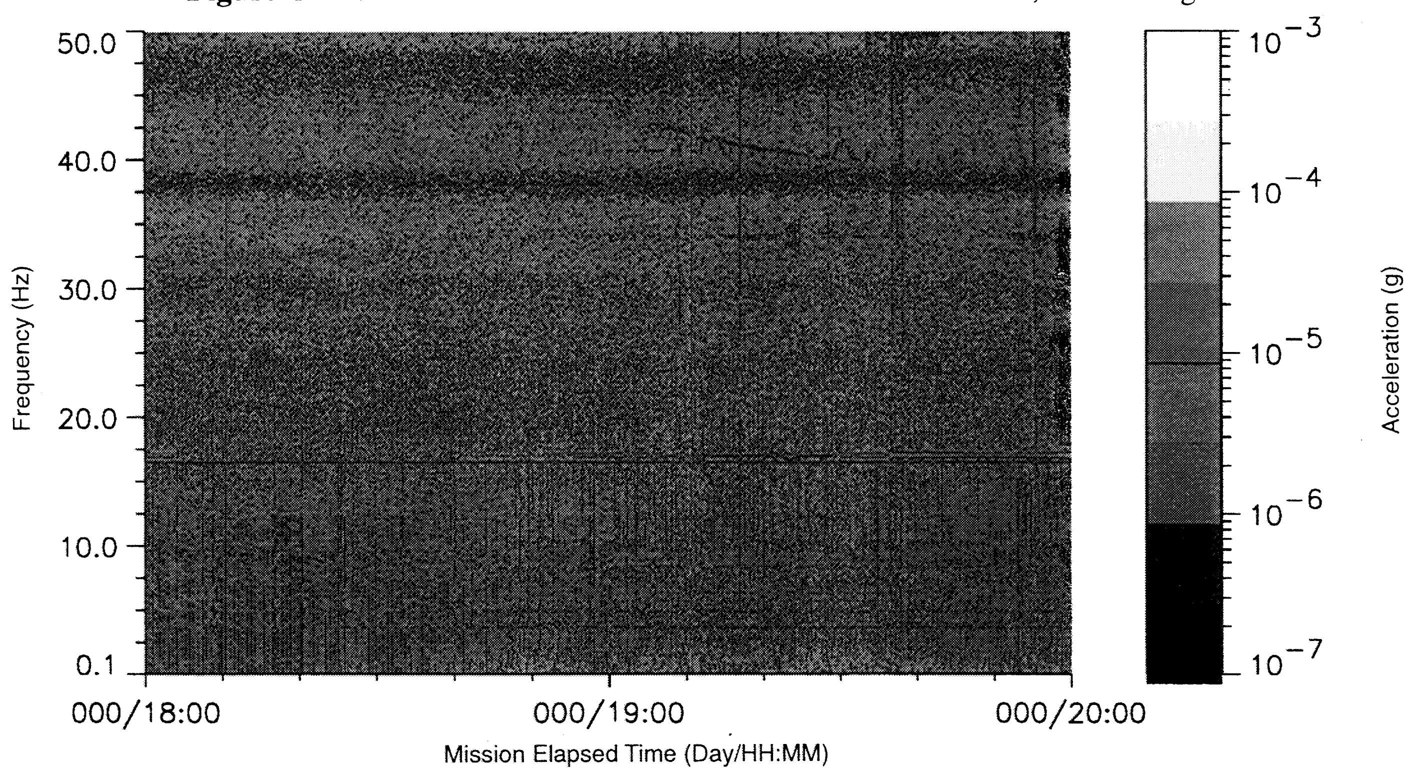

Figure C-7 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

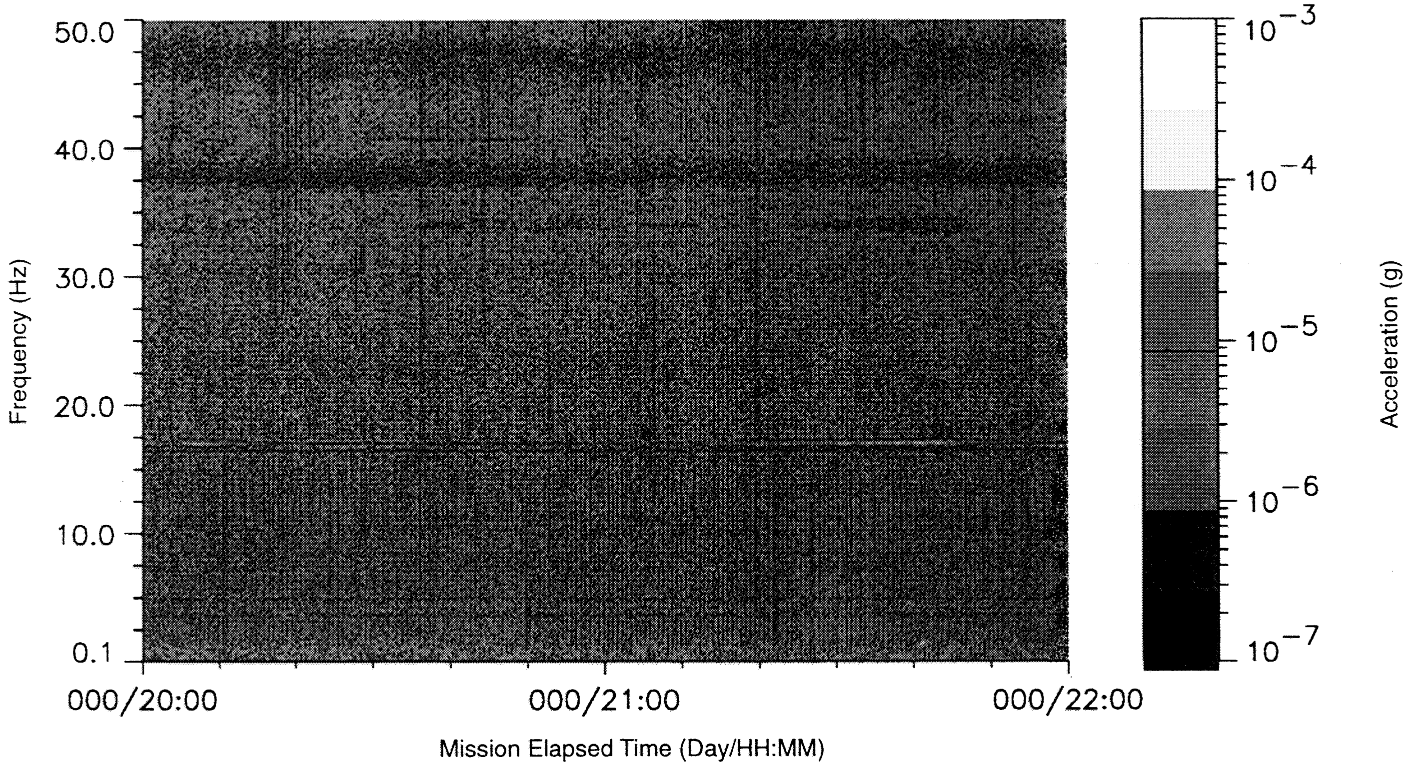

Figure C-8 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

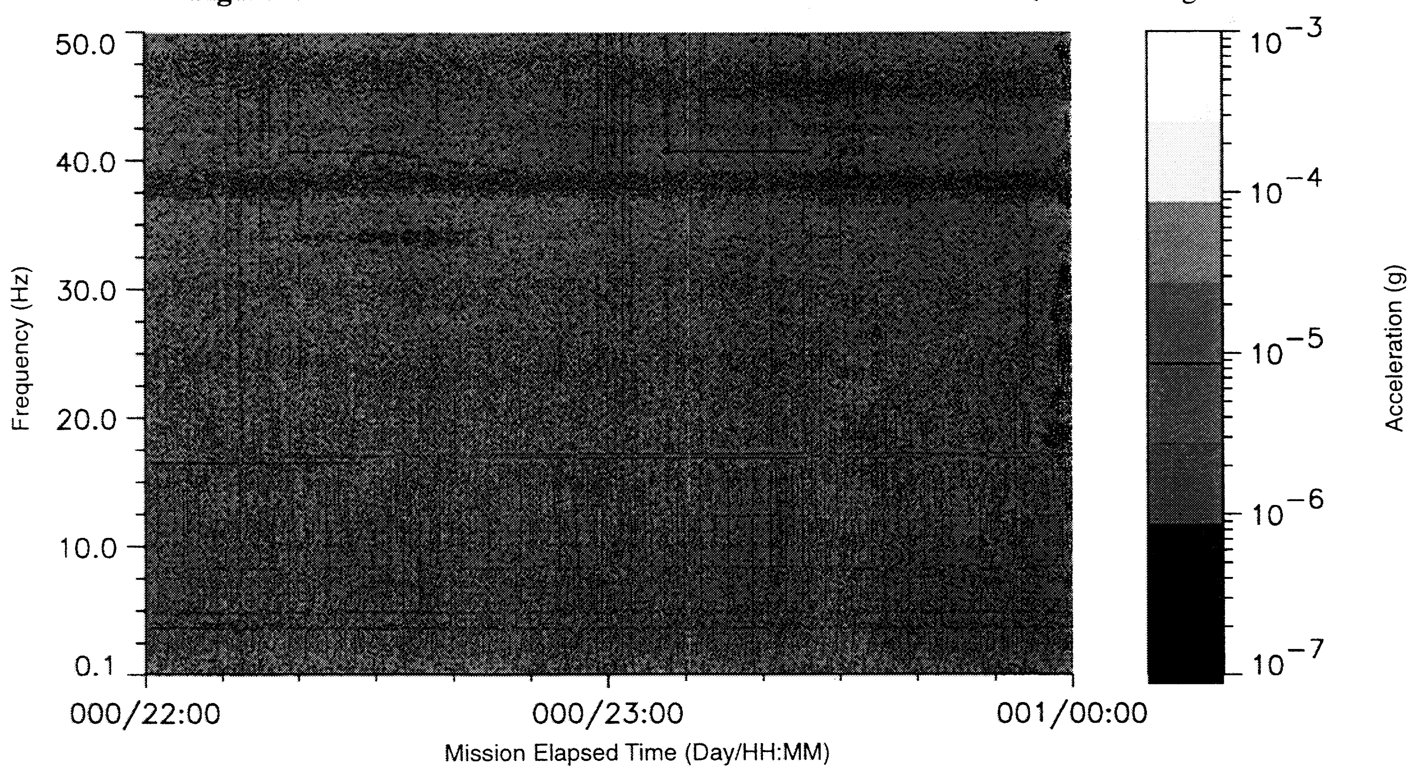

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Figure C-9 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

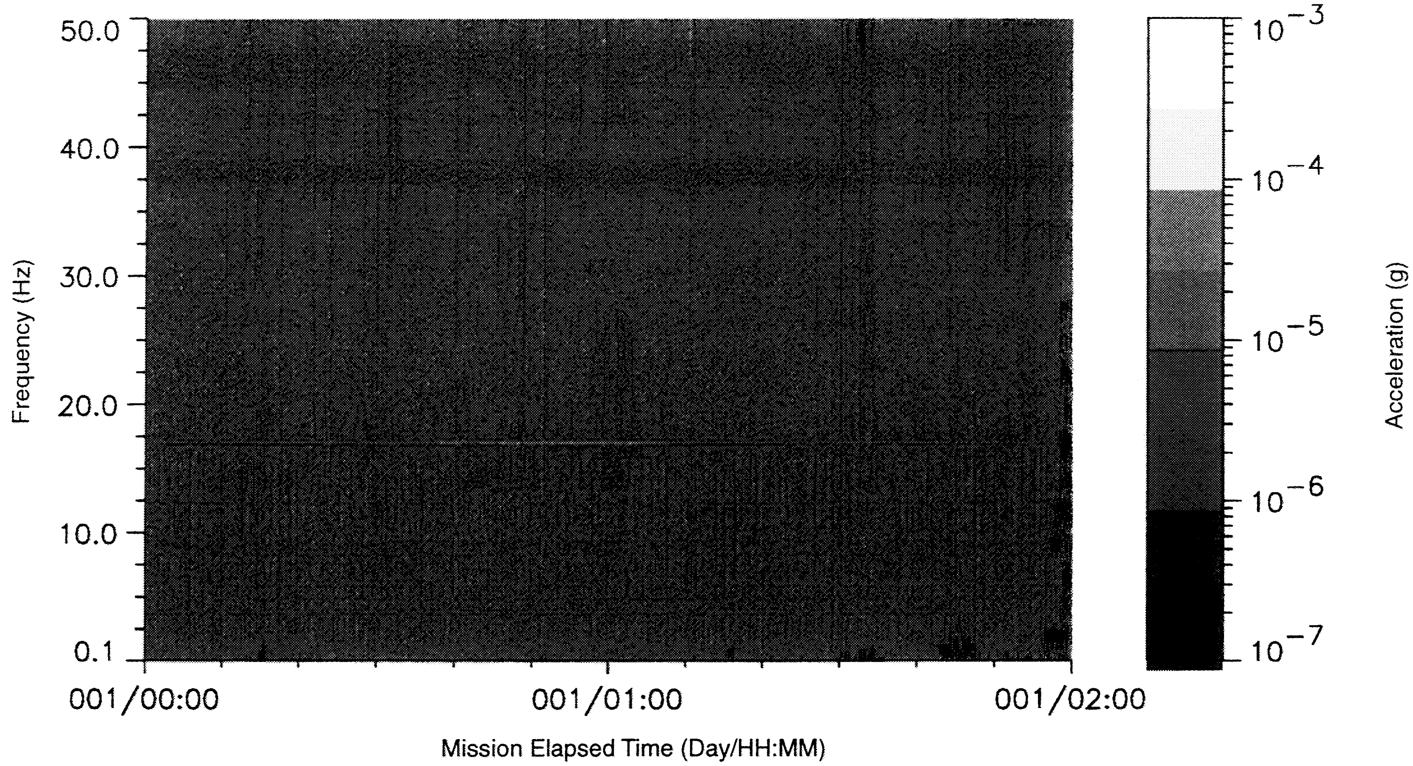

Figure C-10 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

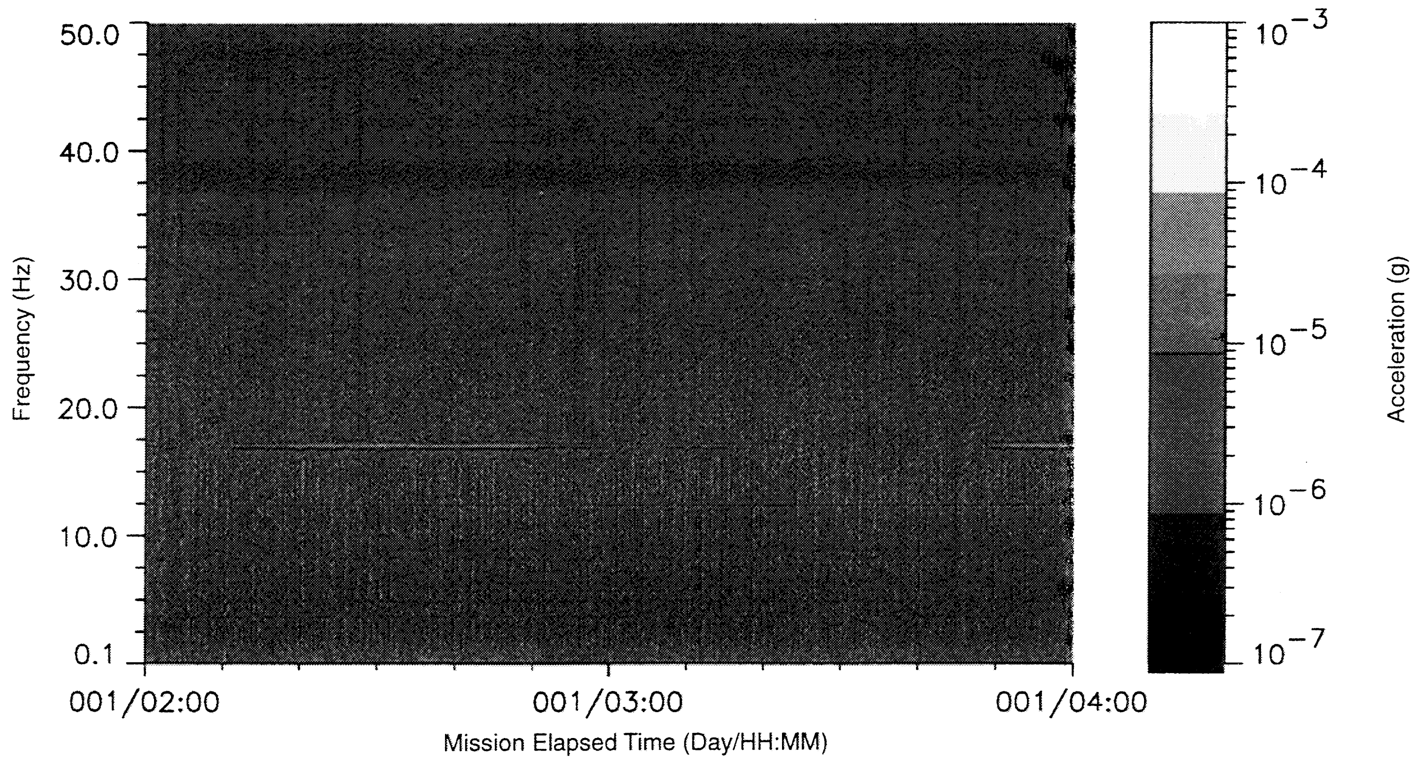

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Figure C-11 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

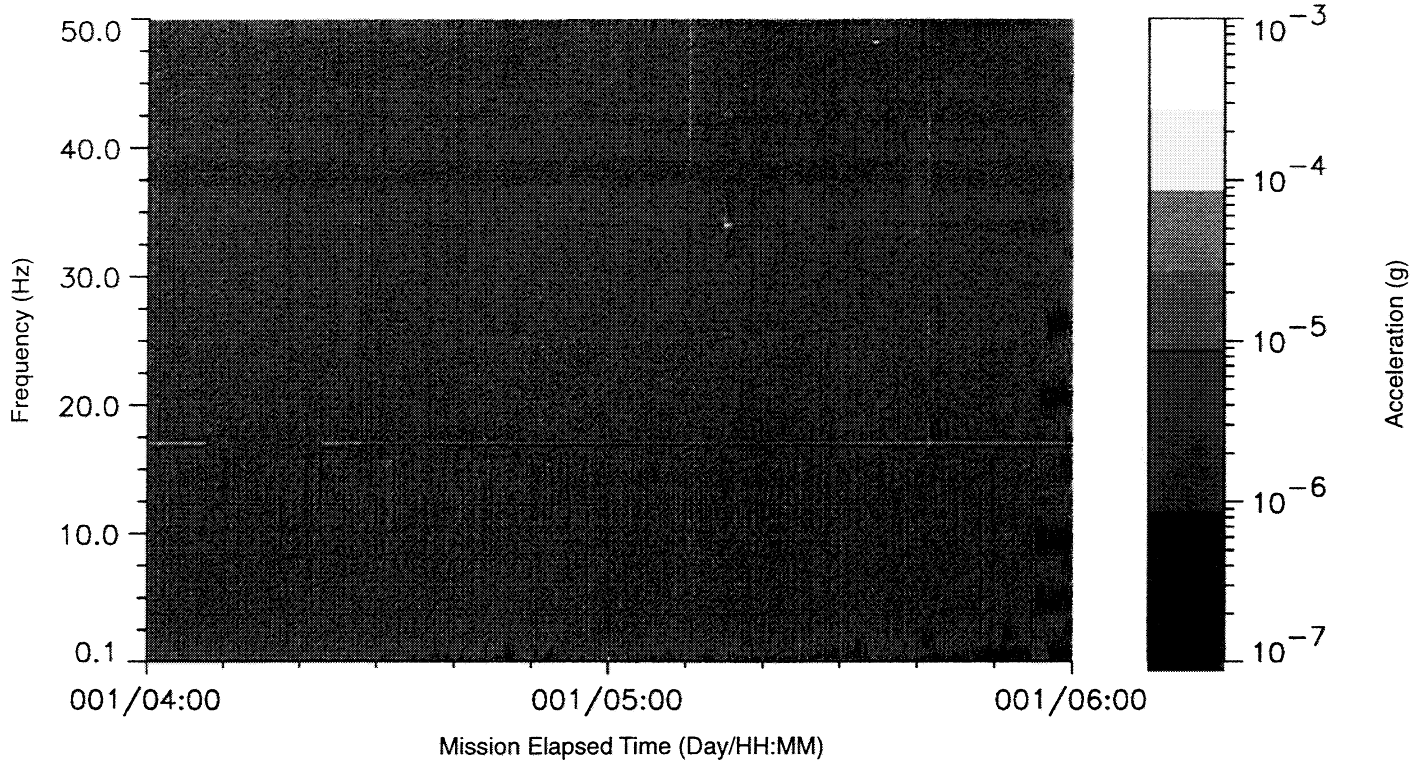

Figure C-12 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

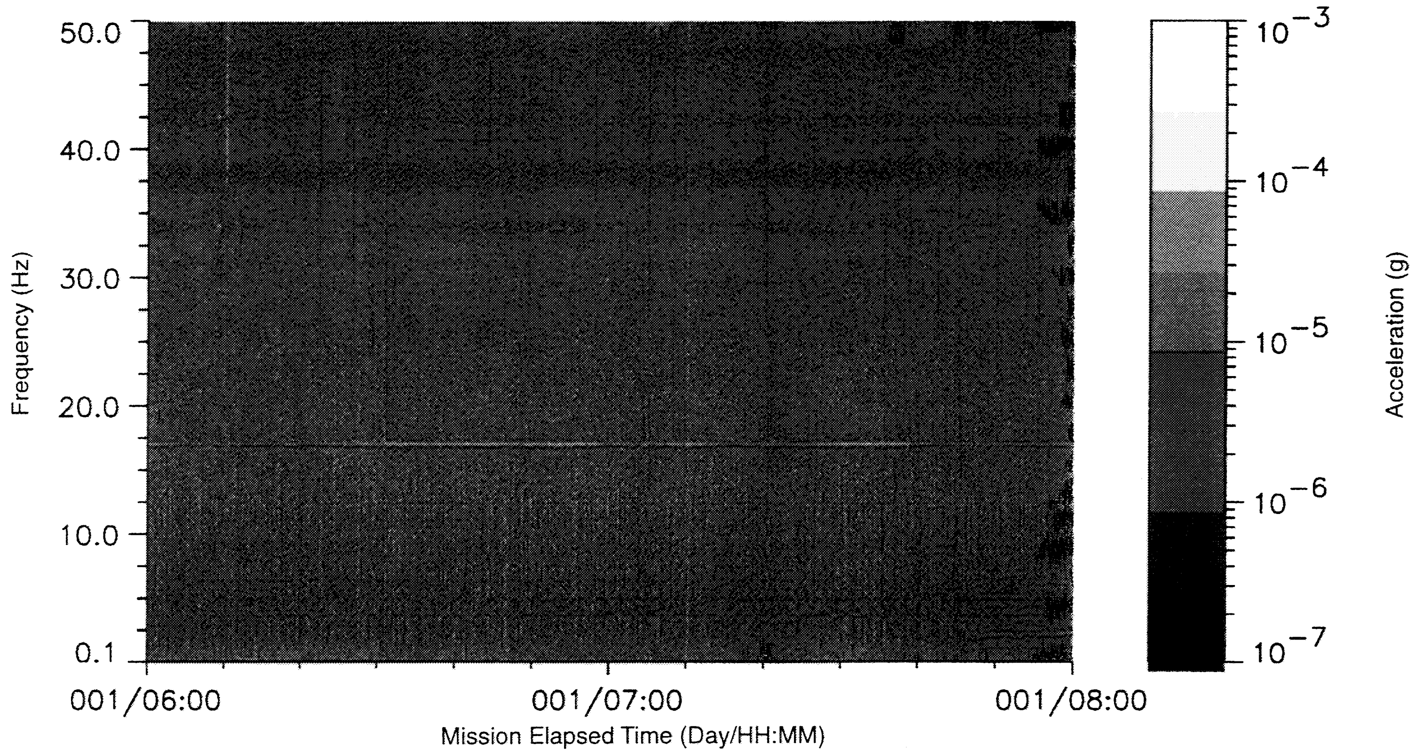

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Figure C-13 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

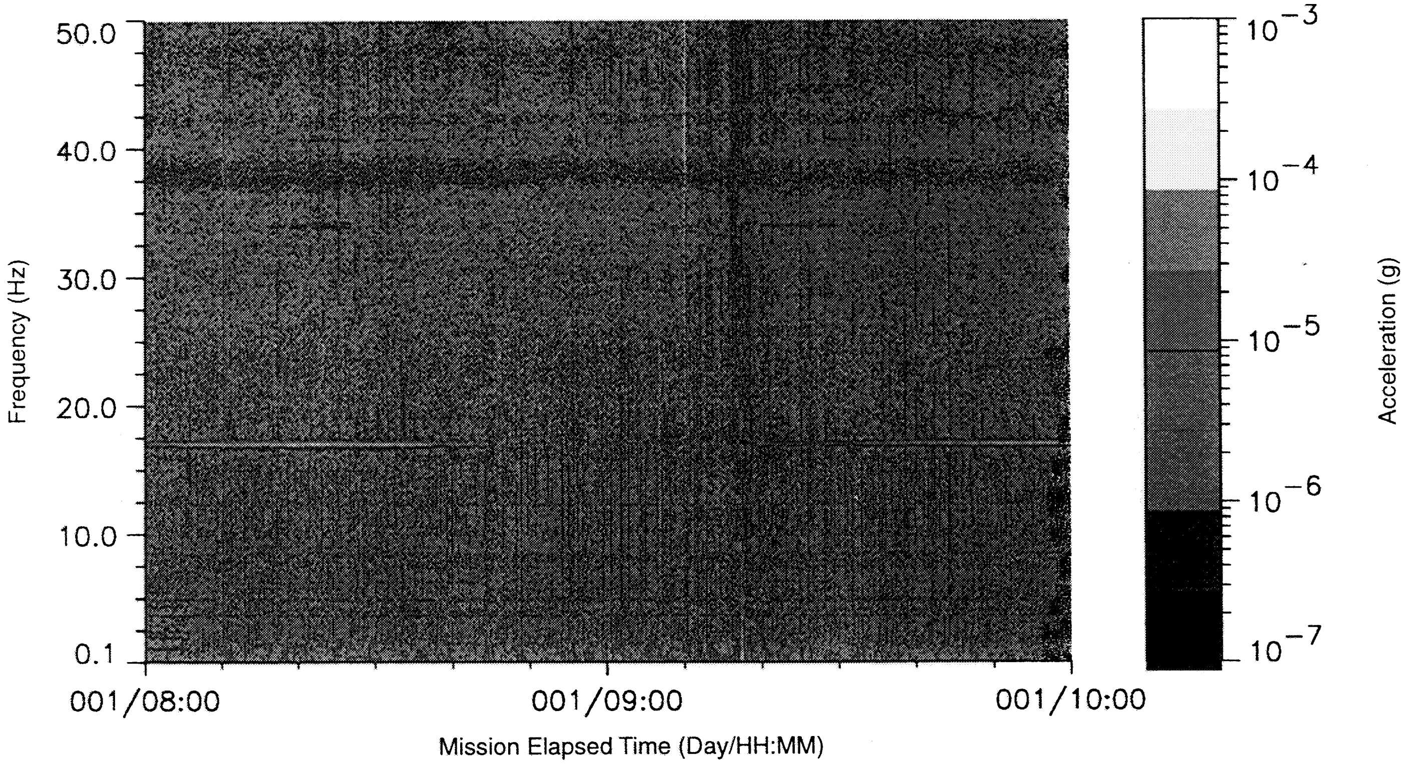

Figure C-14 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

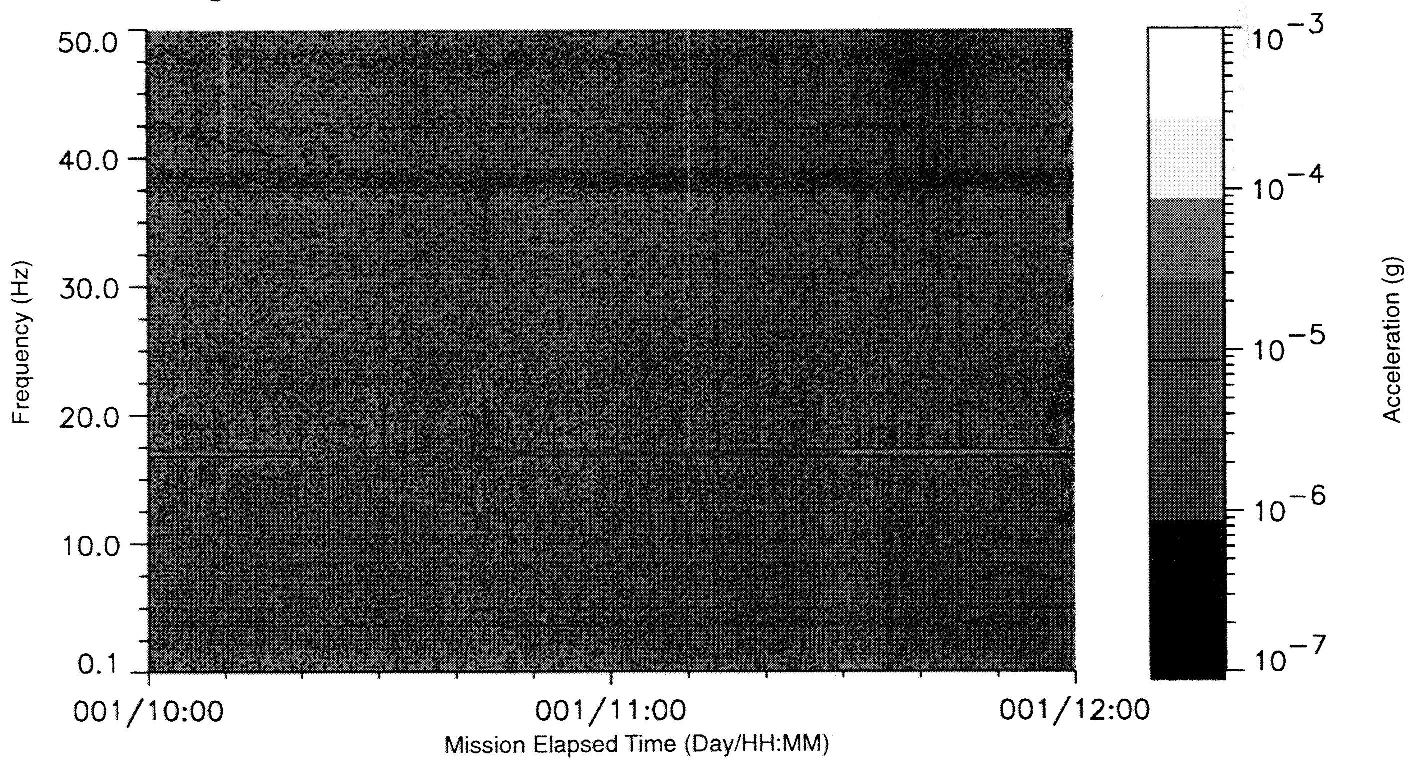

Figure C-15 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

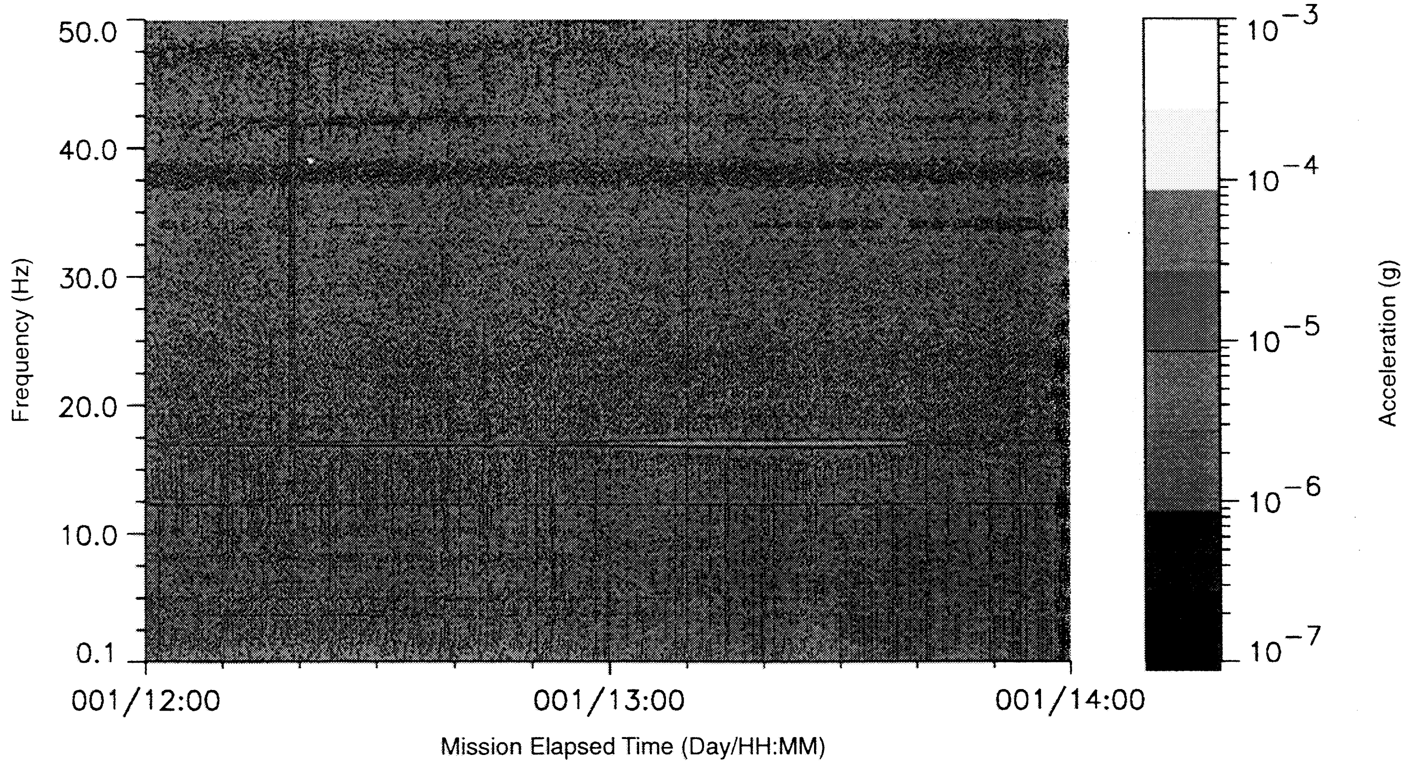

Figure C-16 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

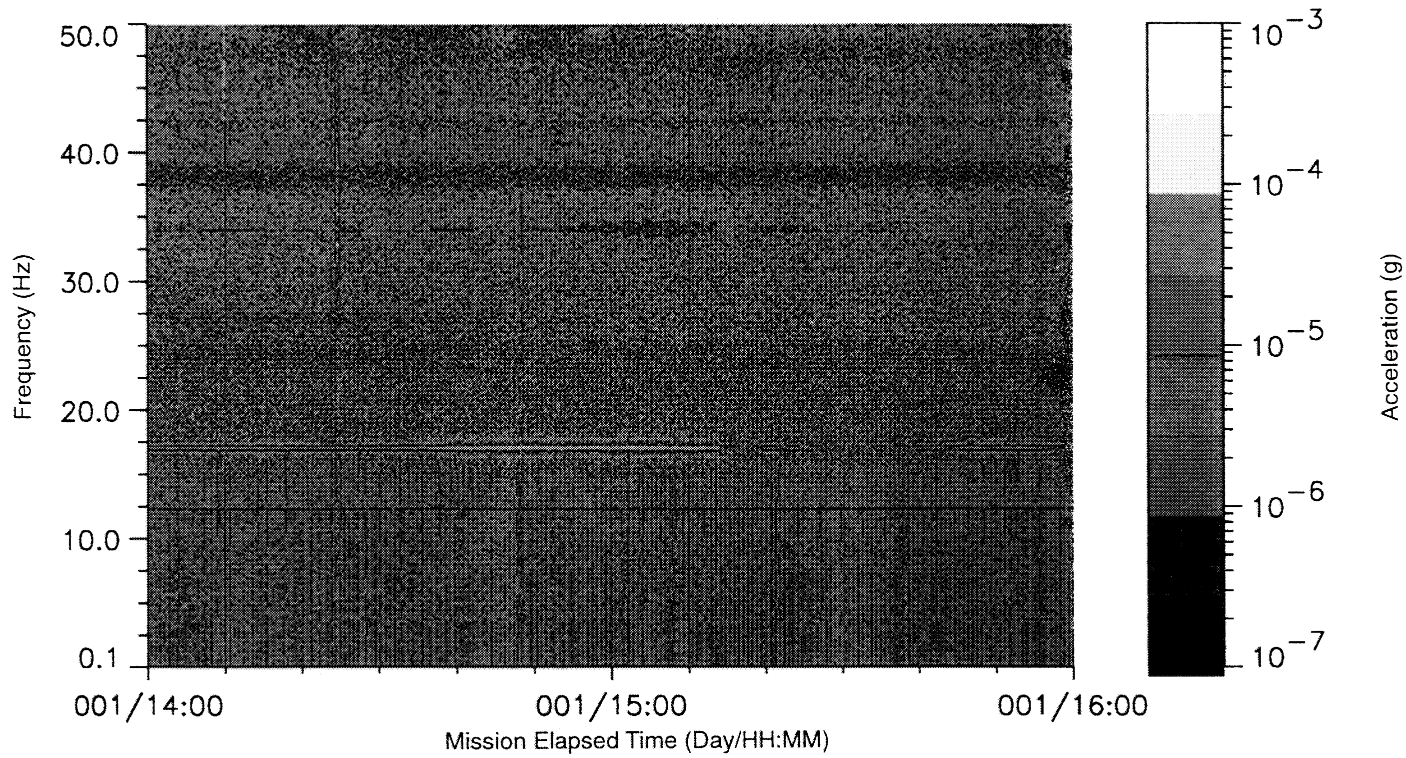

Figure C-17 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

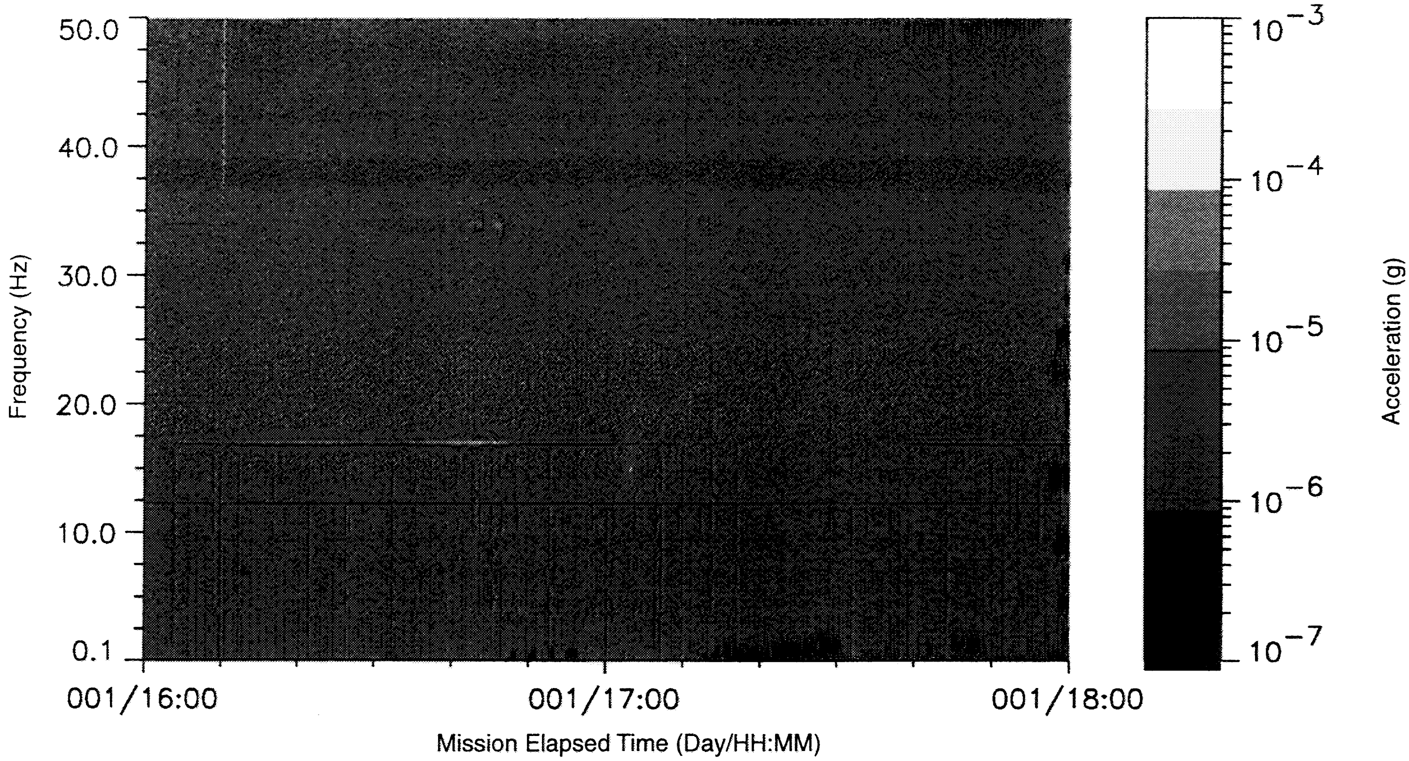

Figure C-18 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

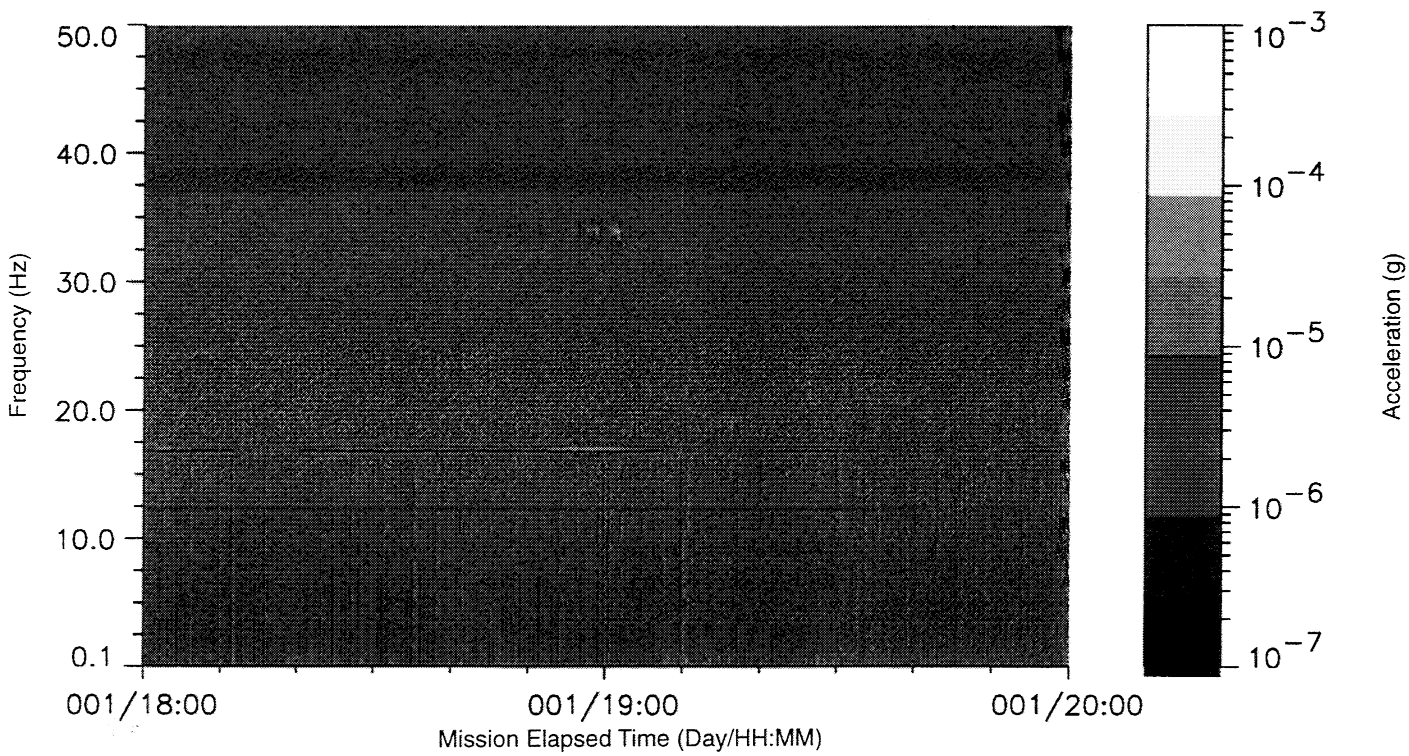

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Figure C-19 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

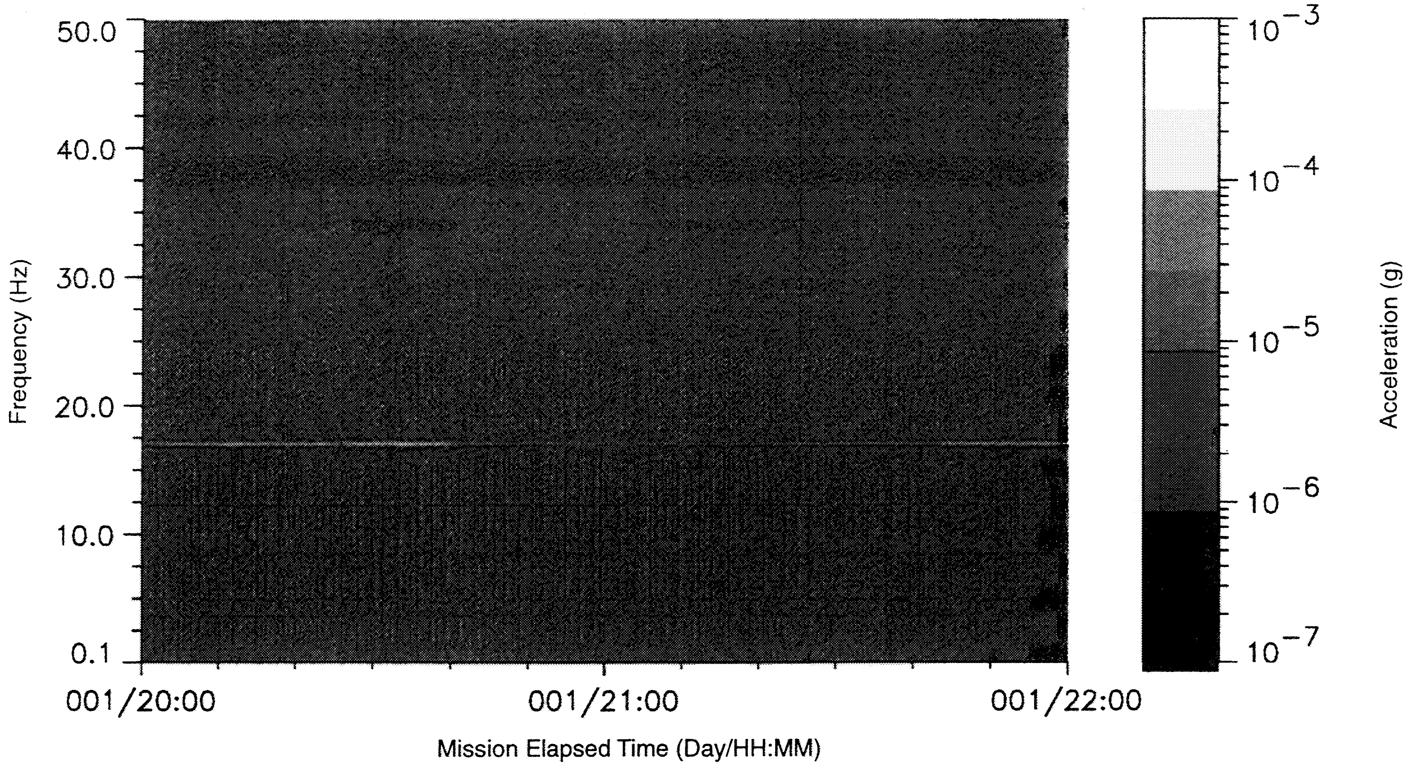

Figure C-20 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

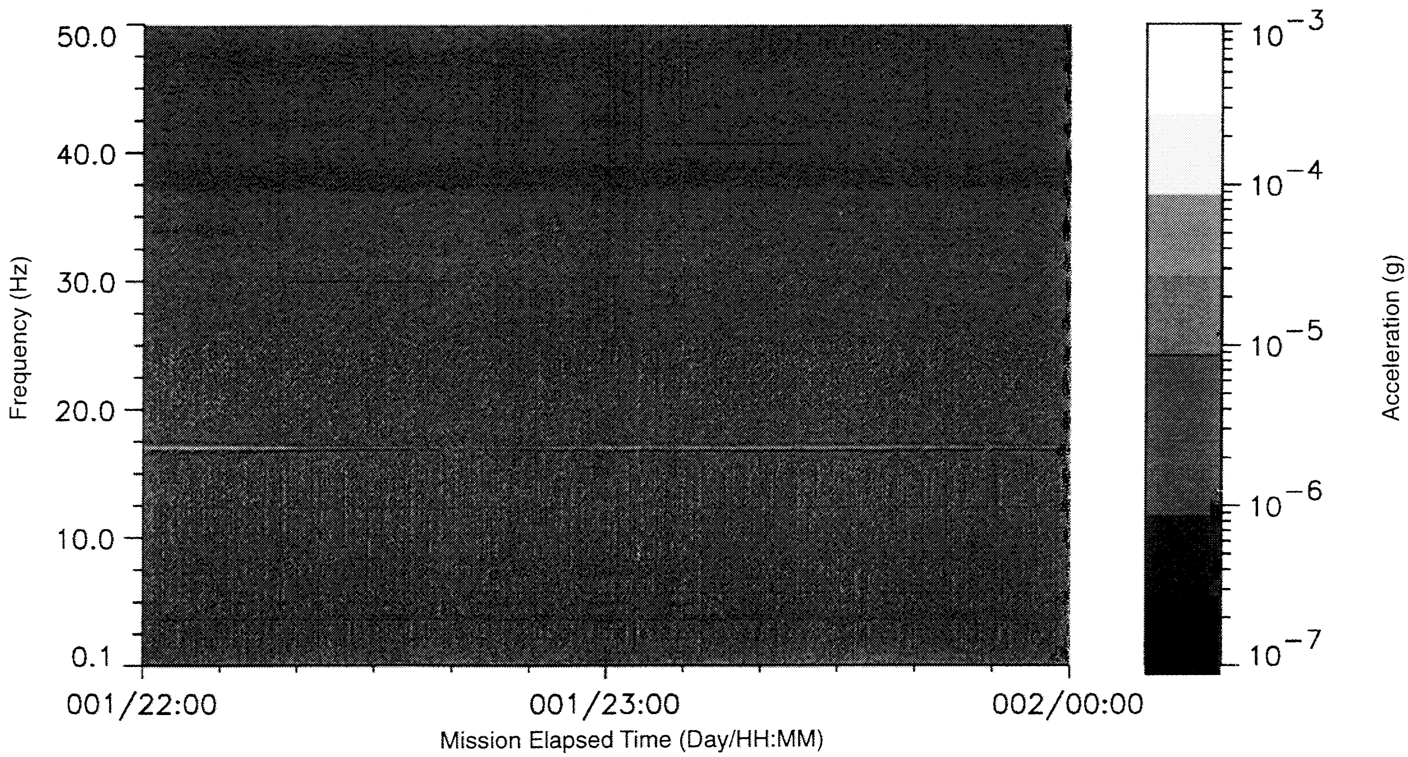

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Figure C-21 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

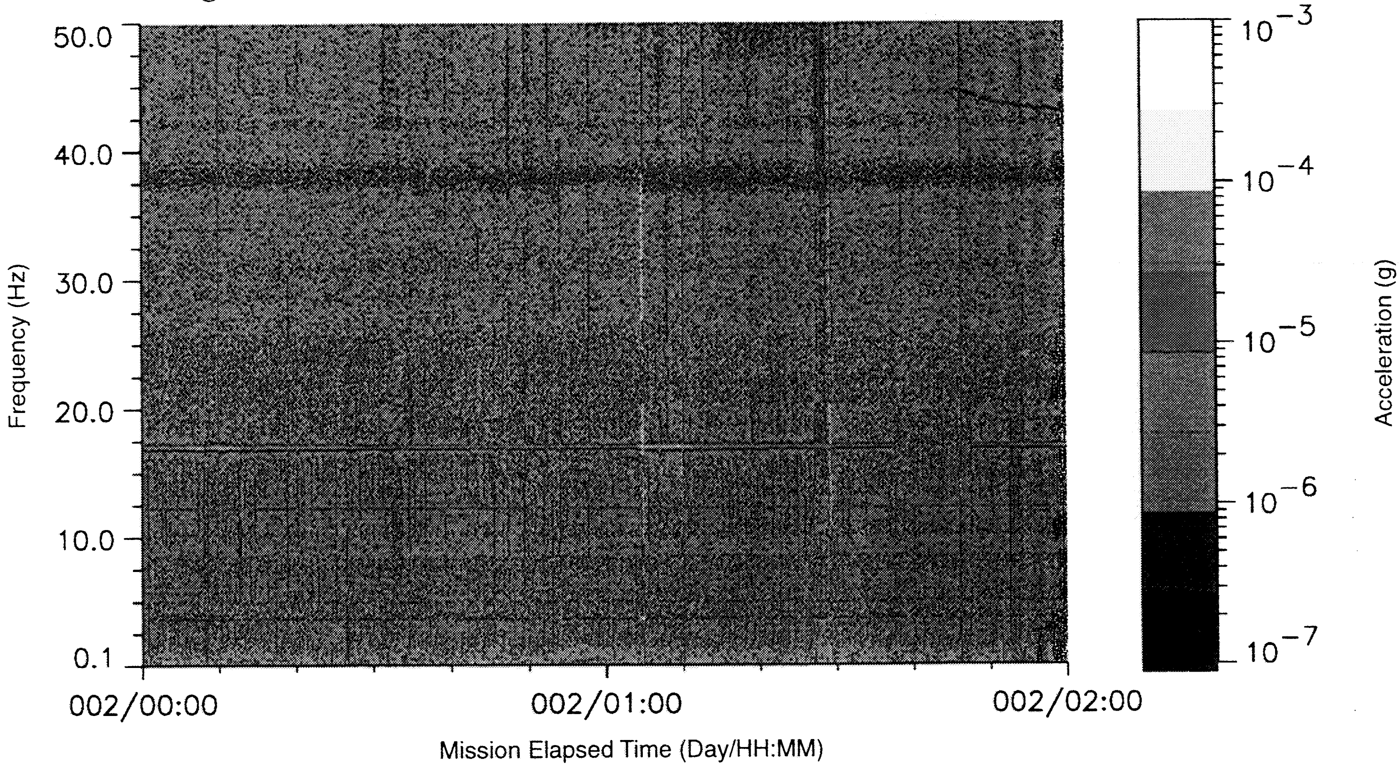

Figure C-22 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

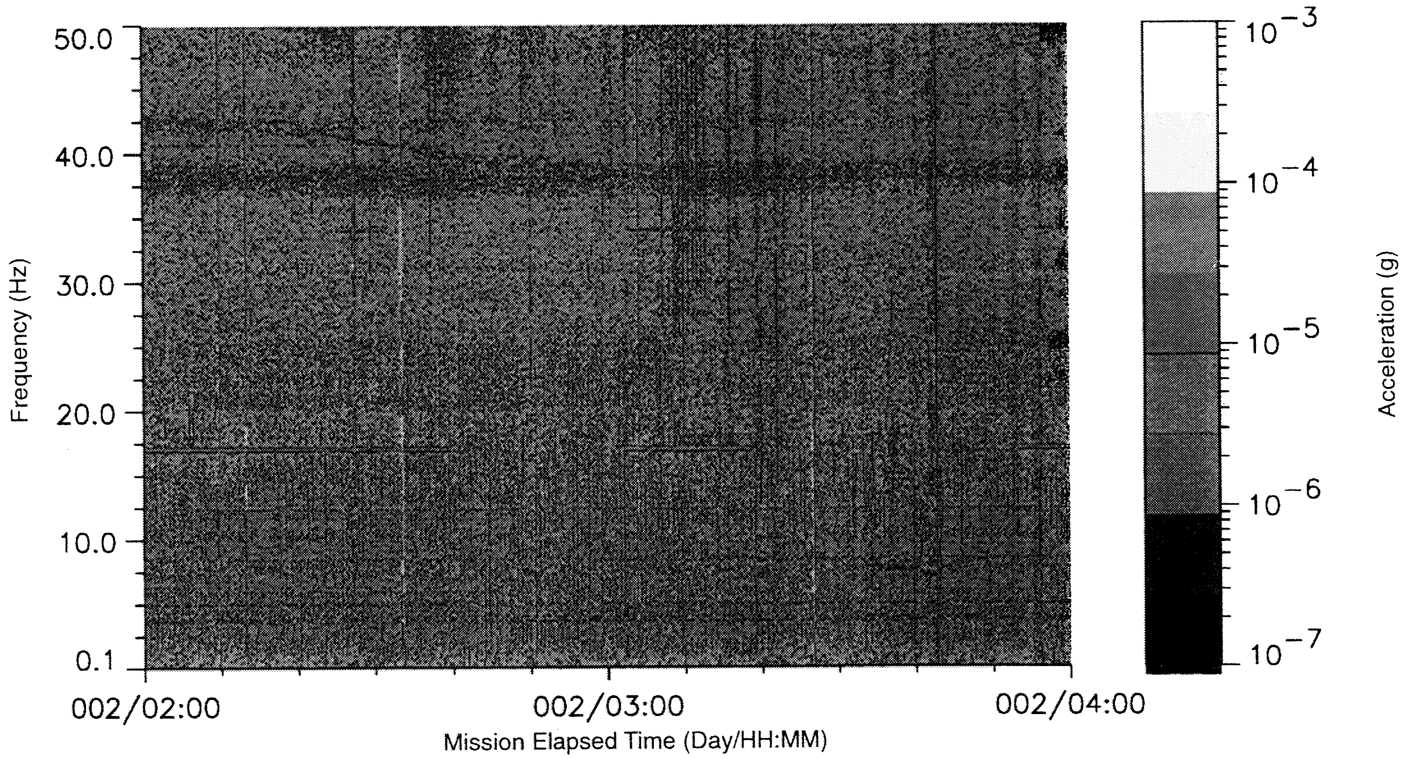

Figure C-23 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

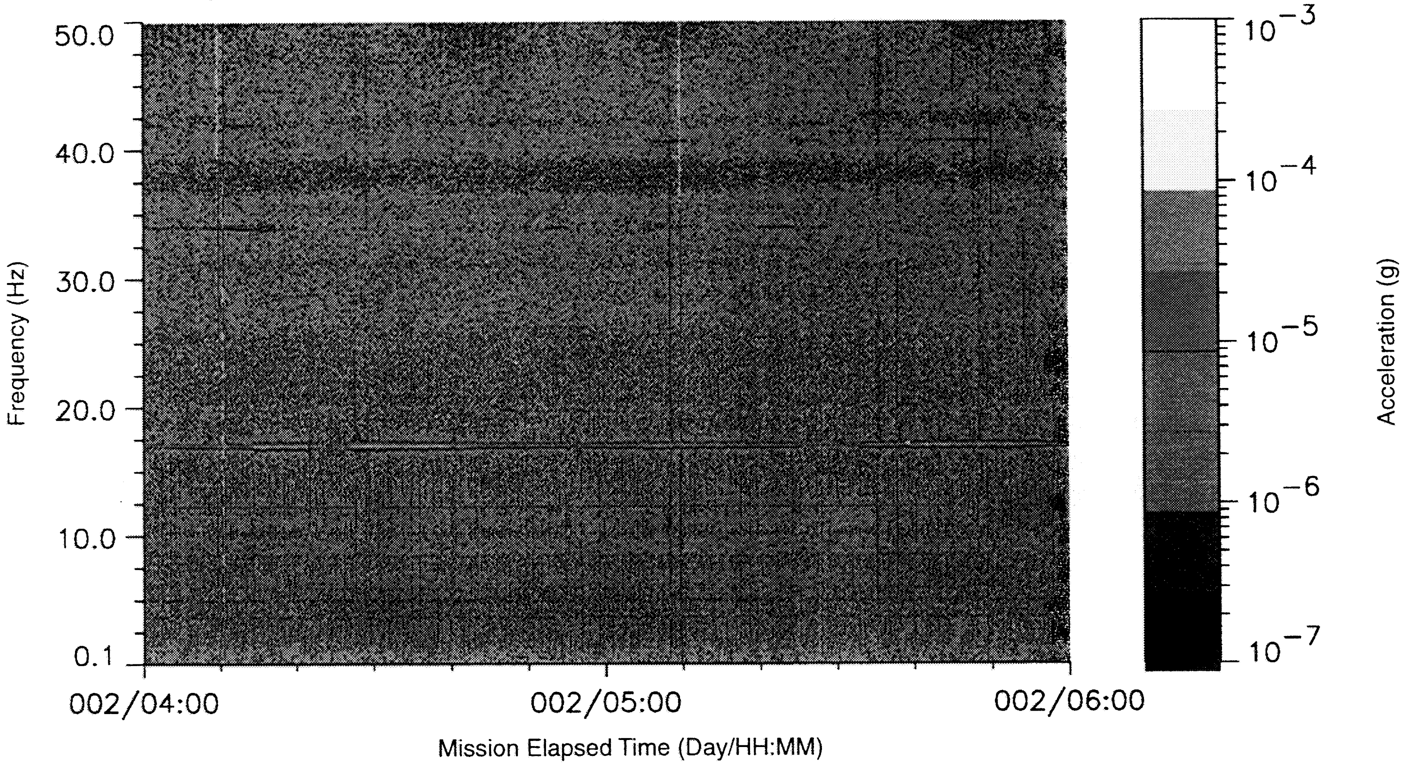

Figure C-24 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

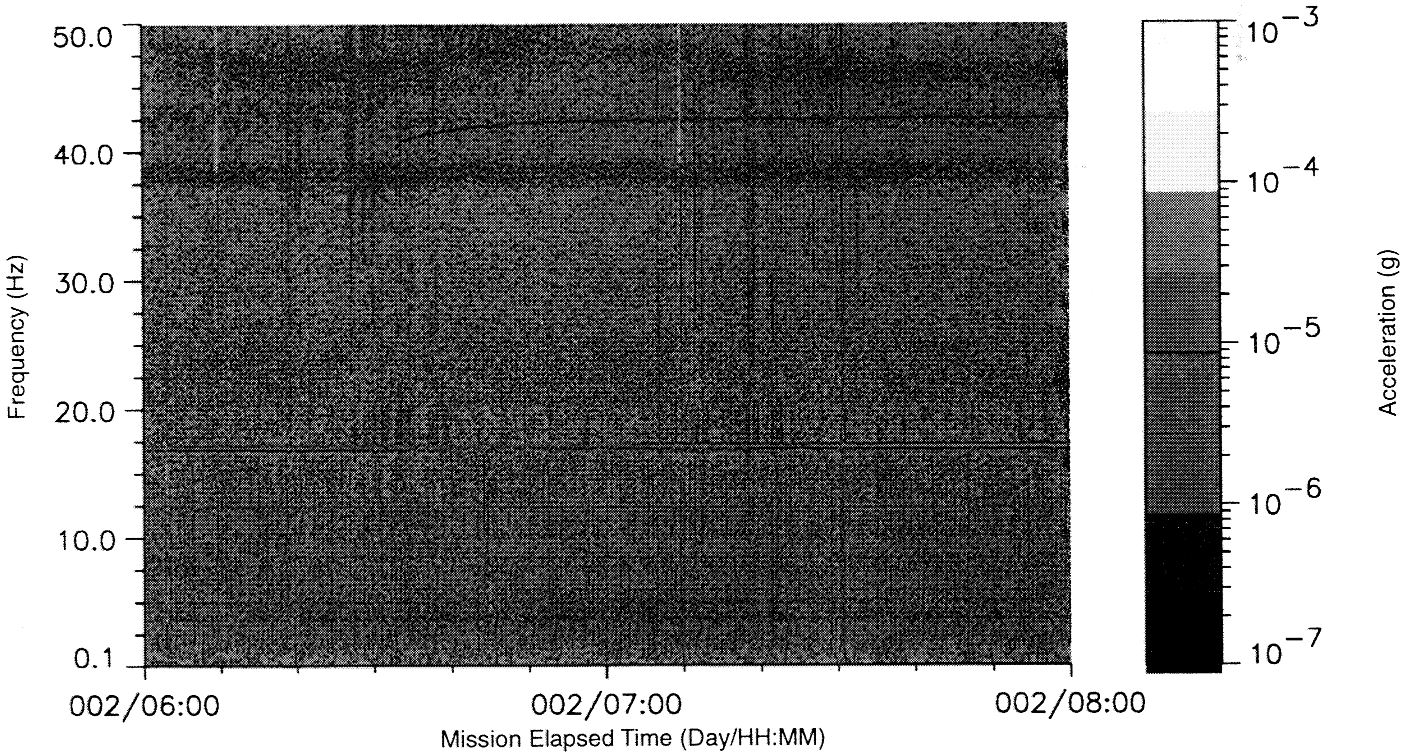

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Figure C-25 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

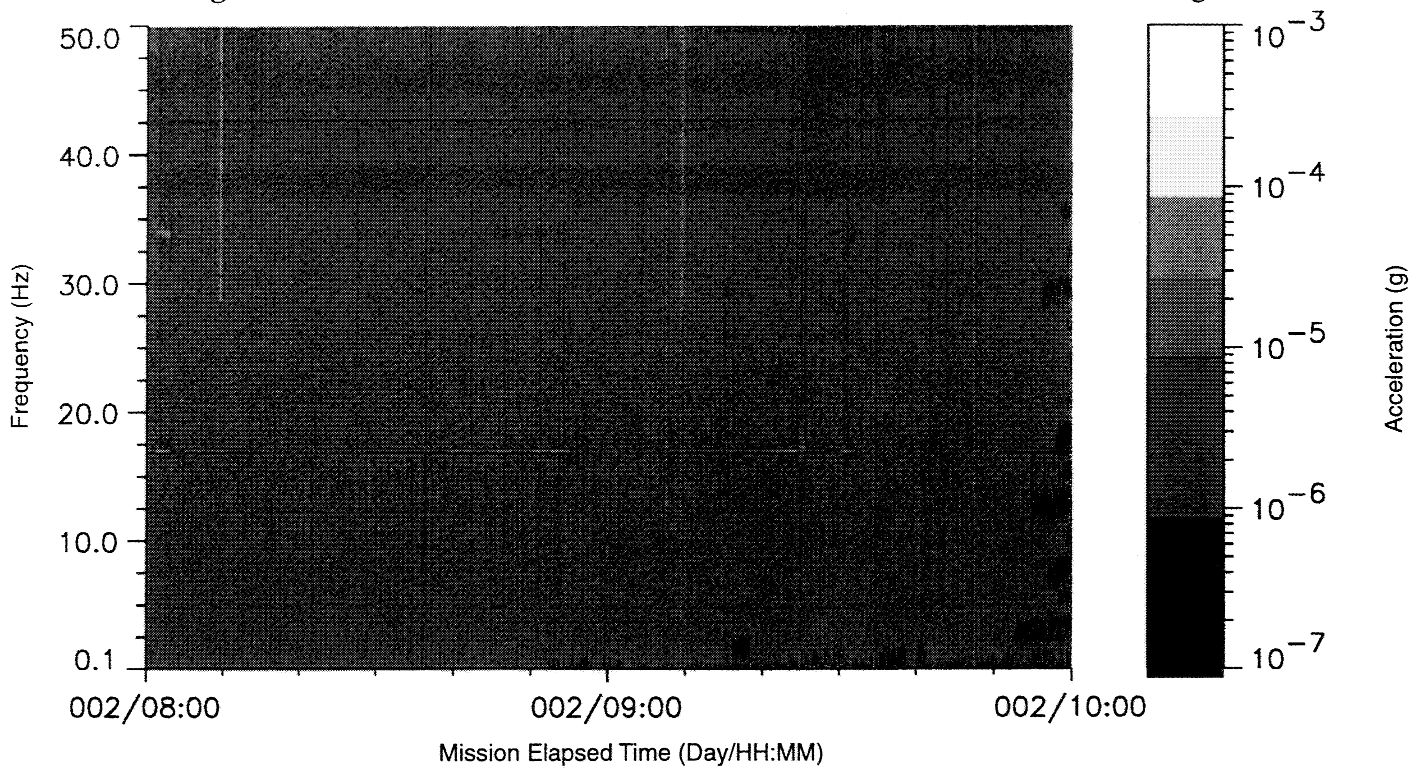

Figure C-26 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

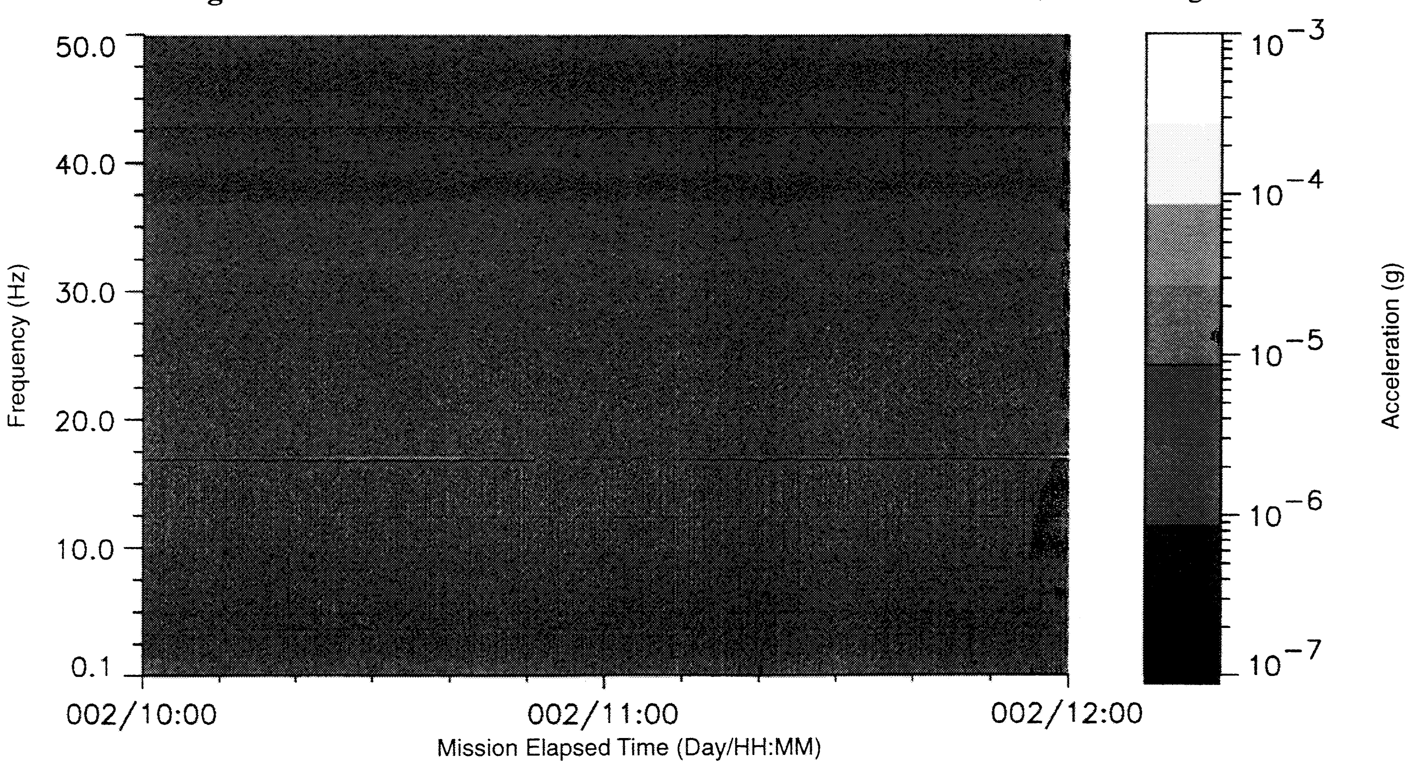

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Figure C-27 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

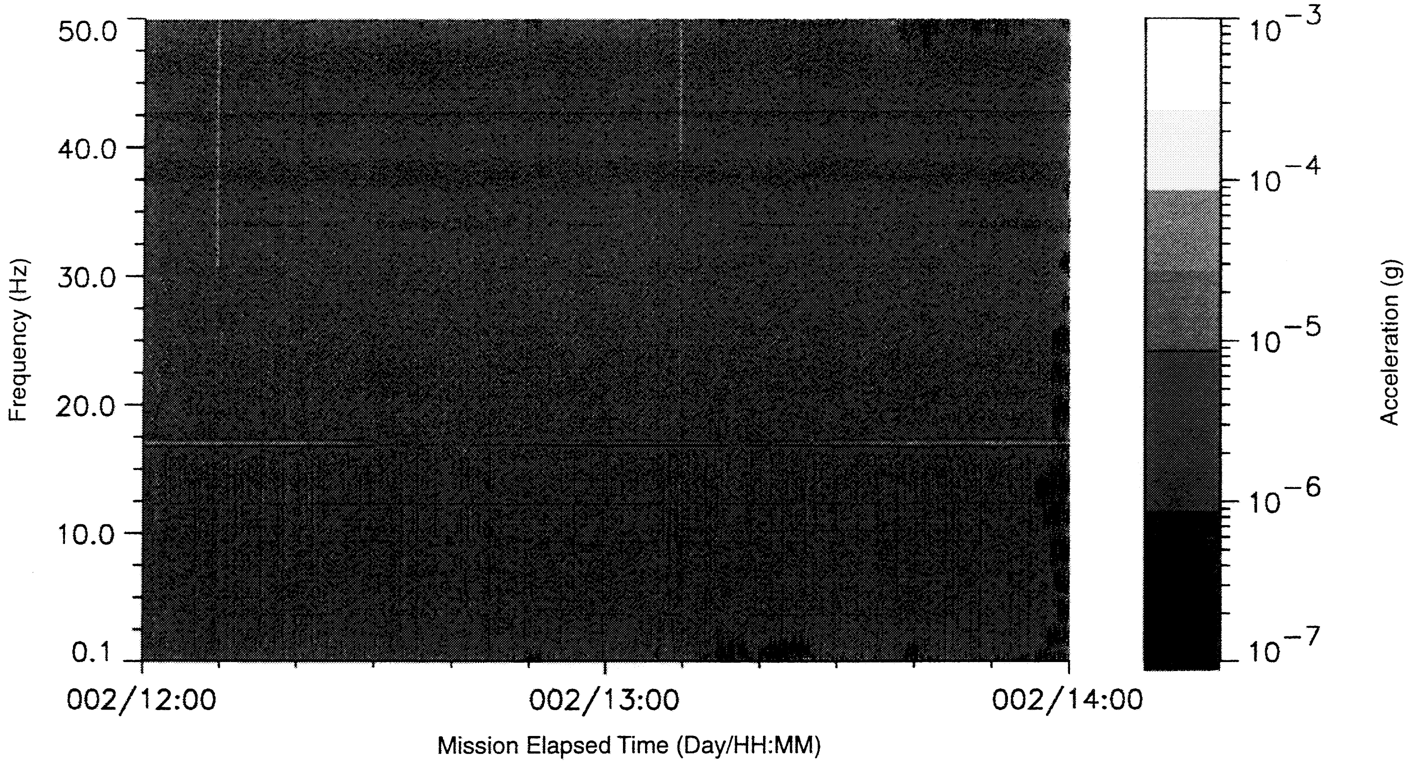

Figure C-28 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

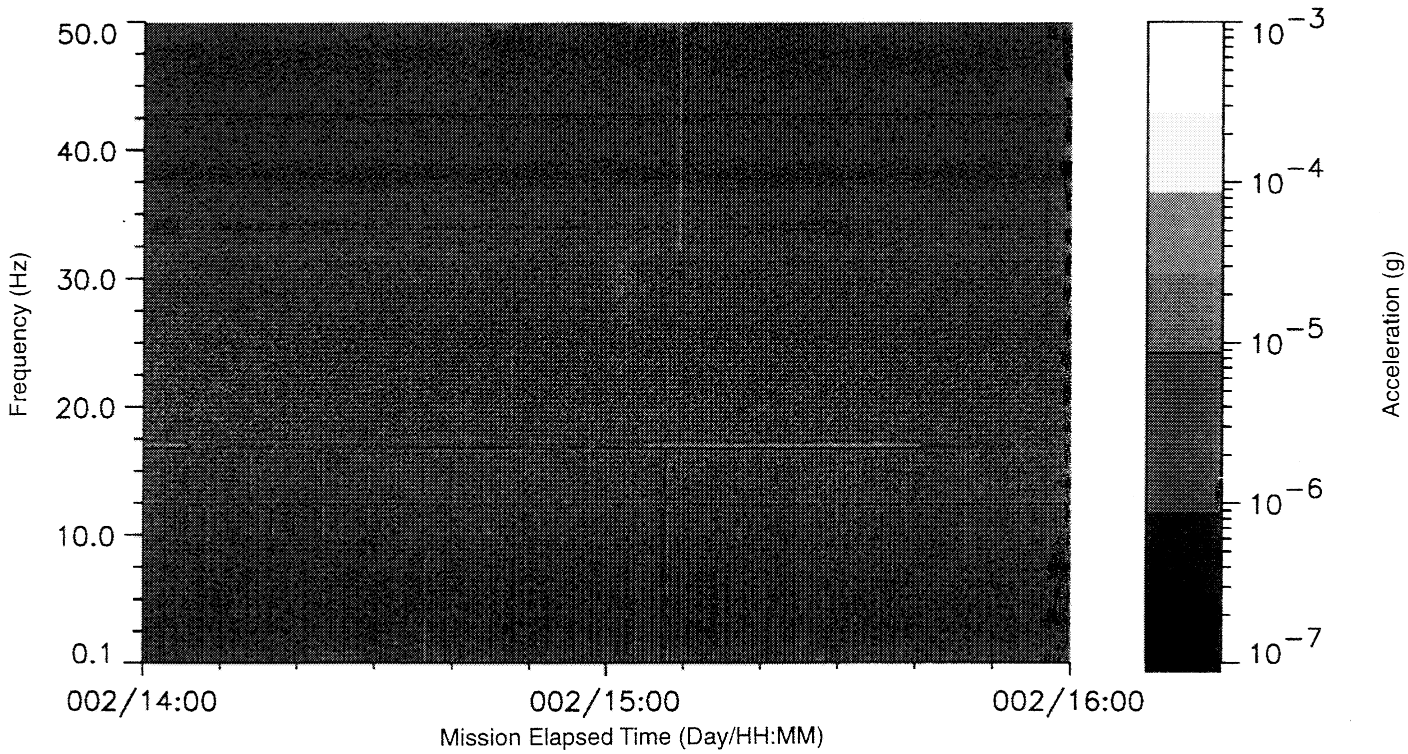

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Figure C-29 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

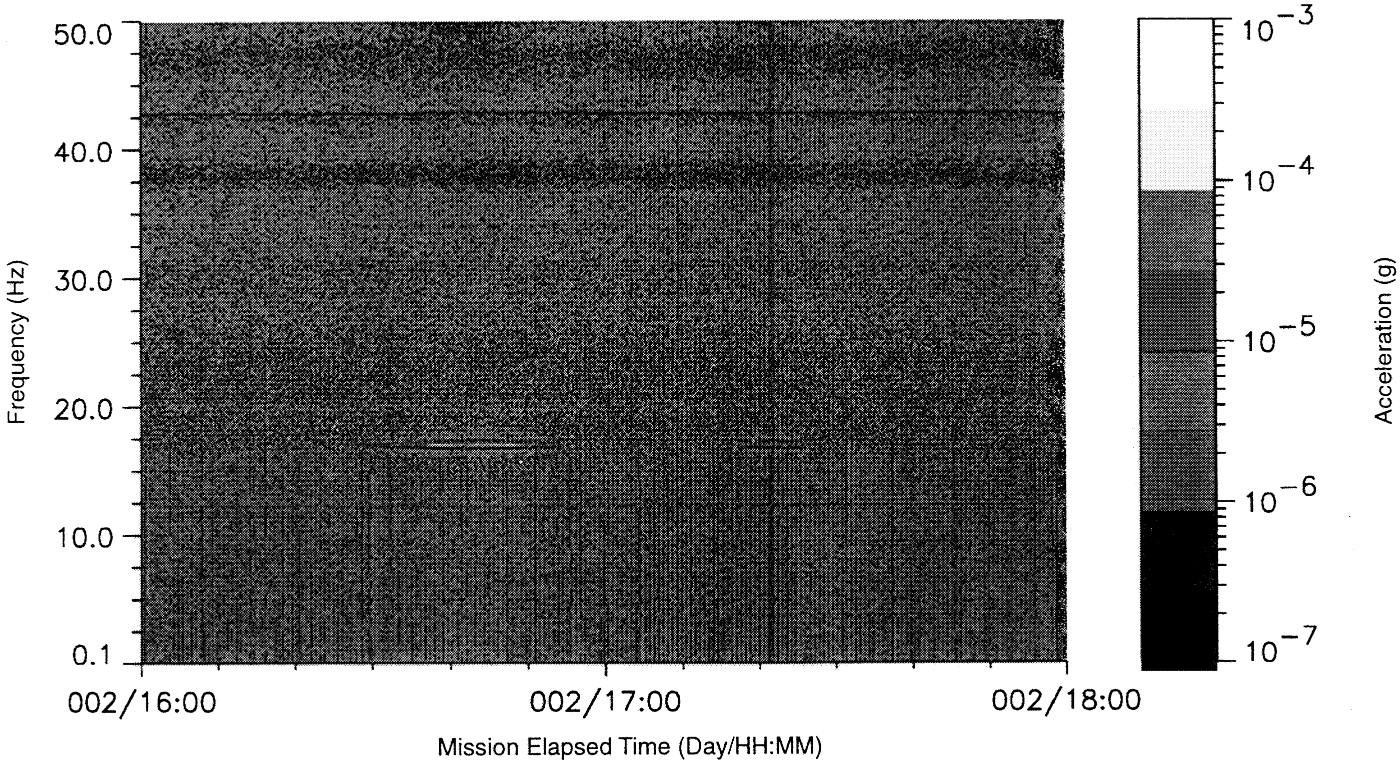

Figure C-30 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

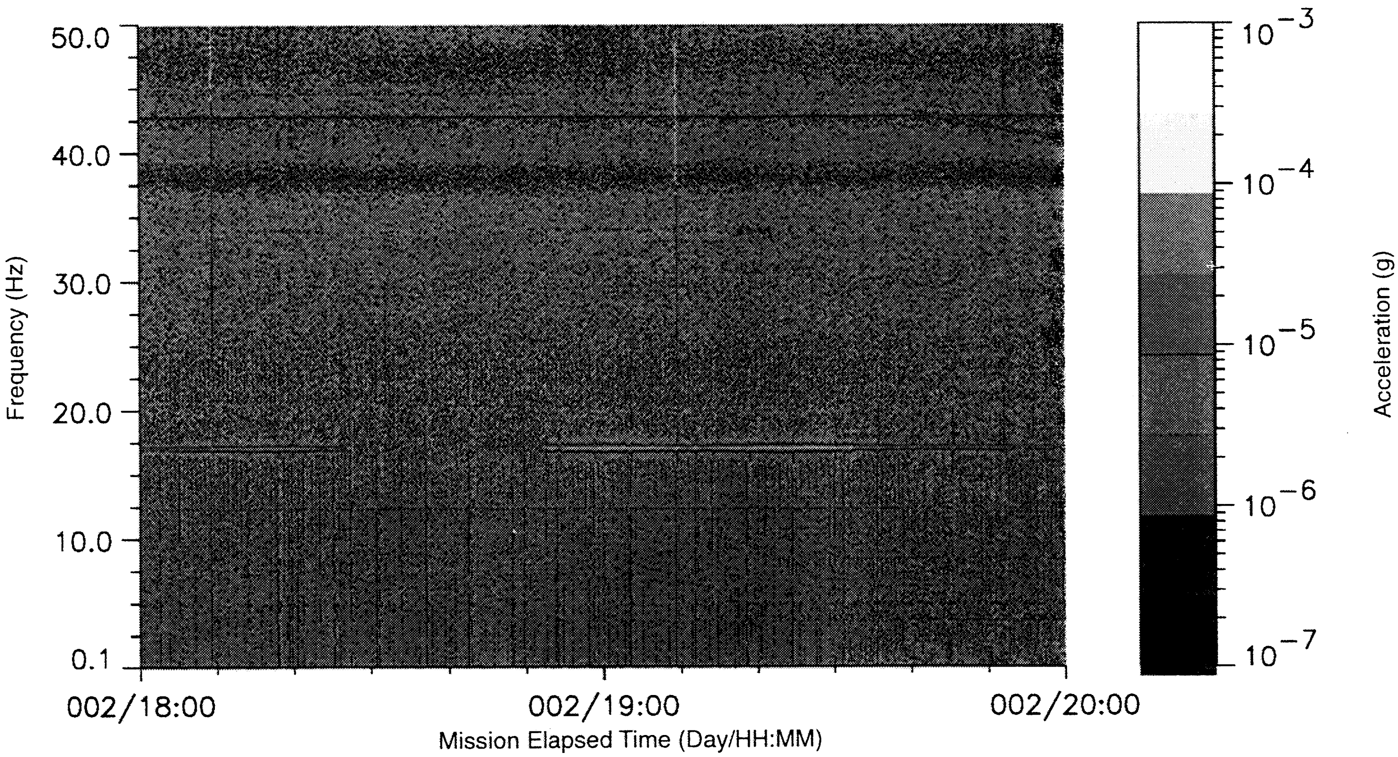

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Figure C-31 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

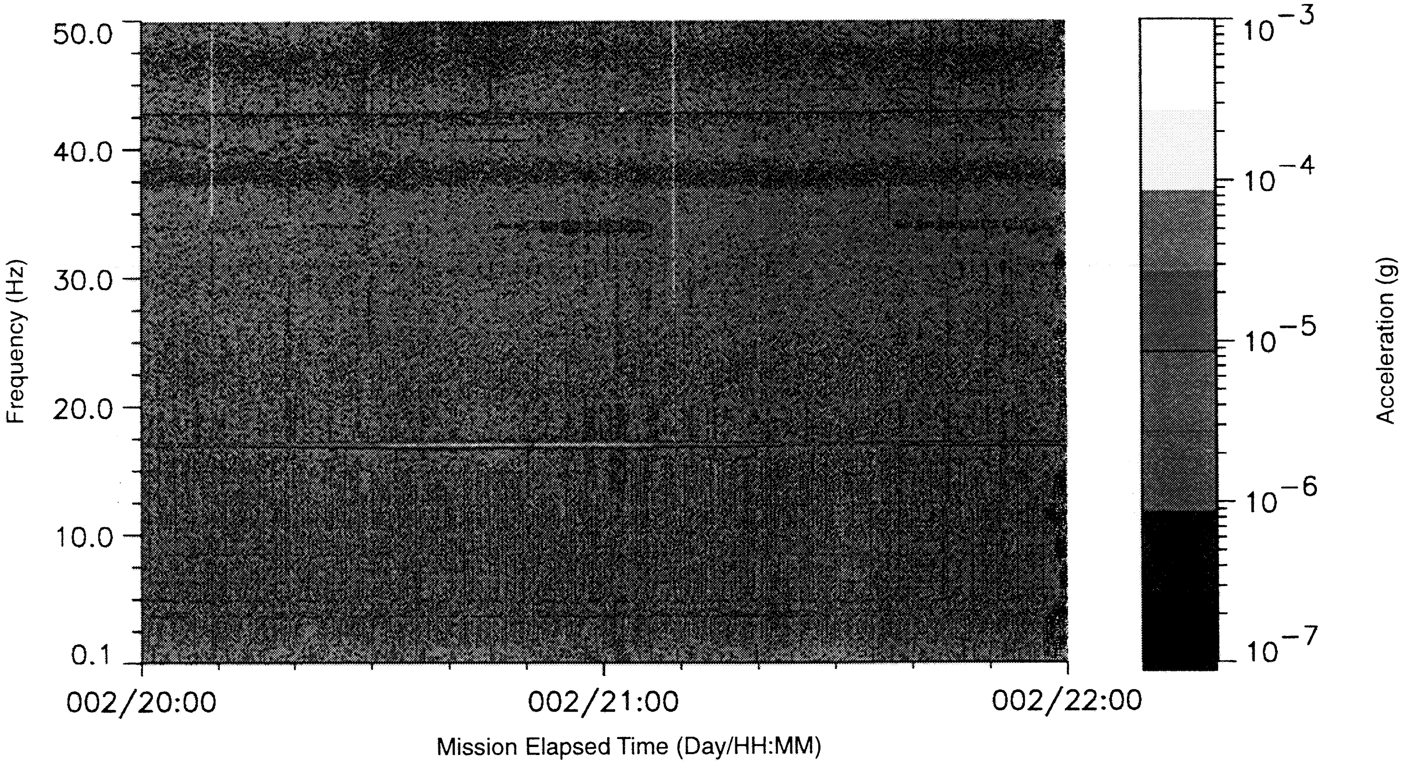

Figure C-32 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

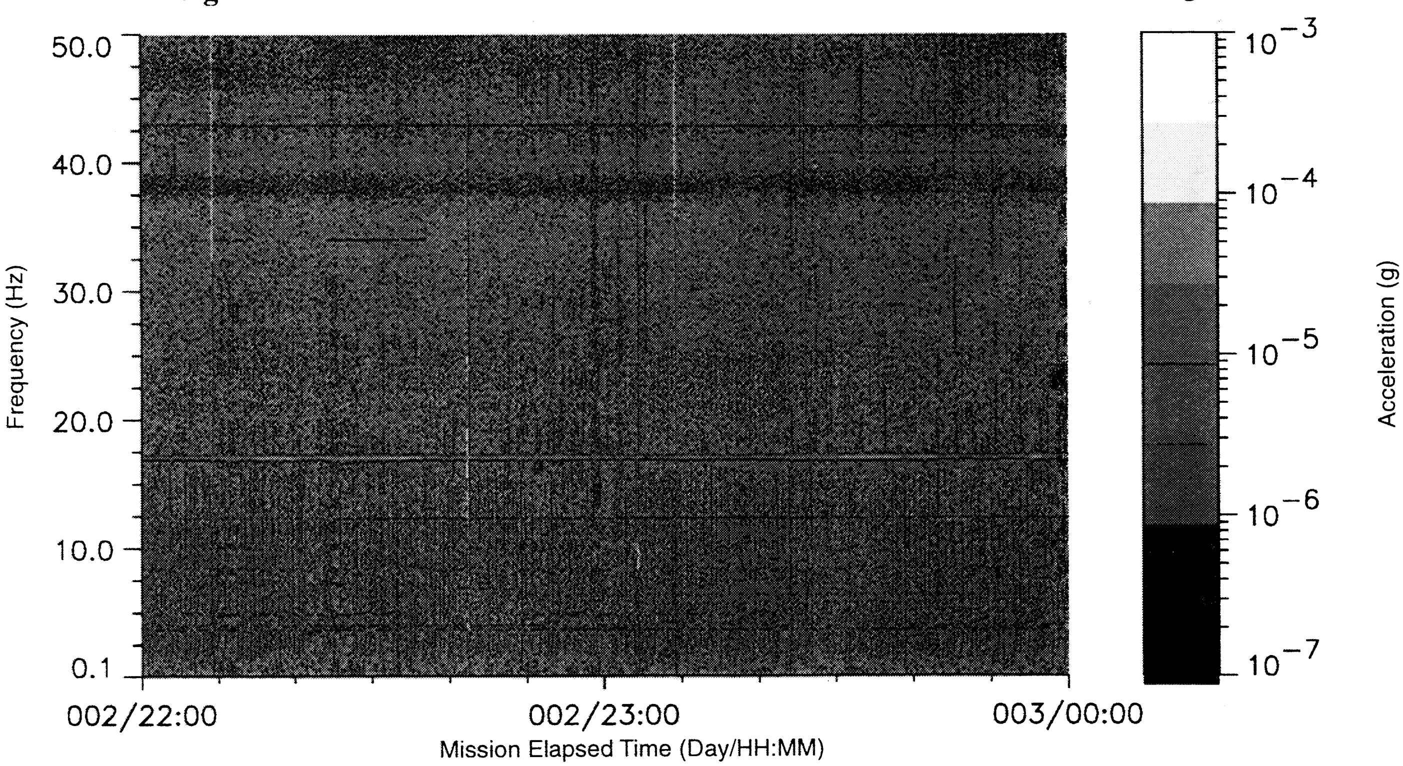

Figure C-33 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

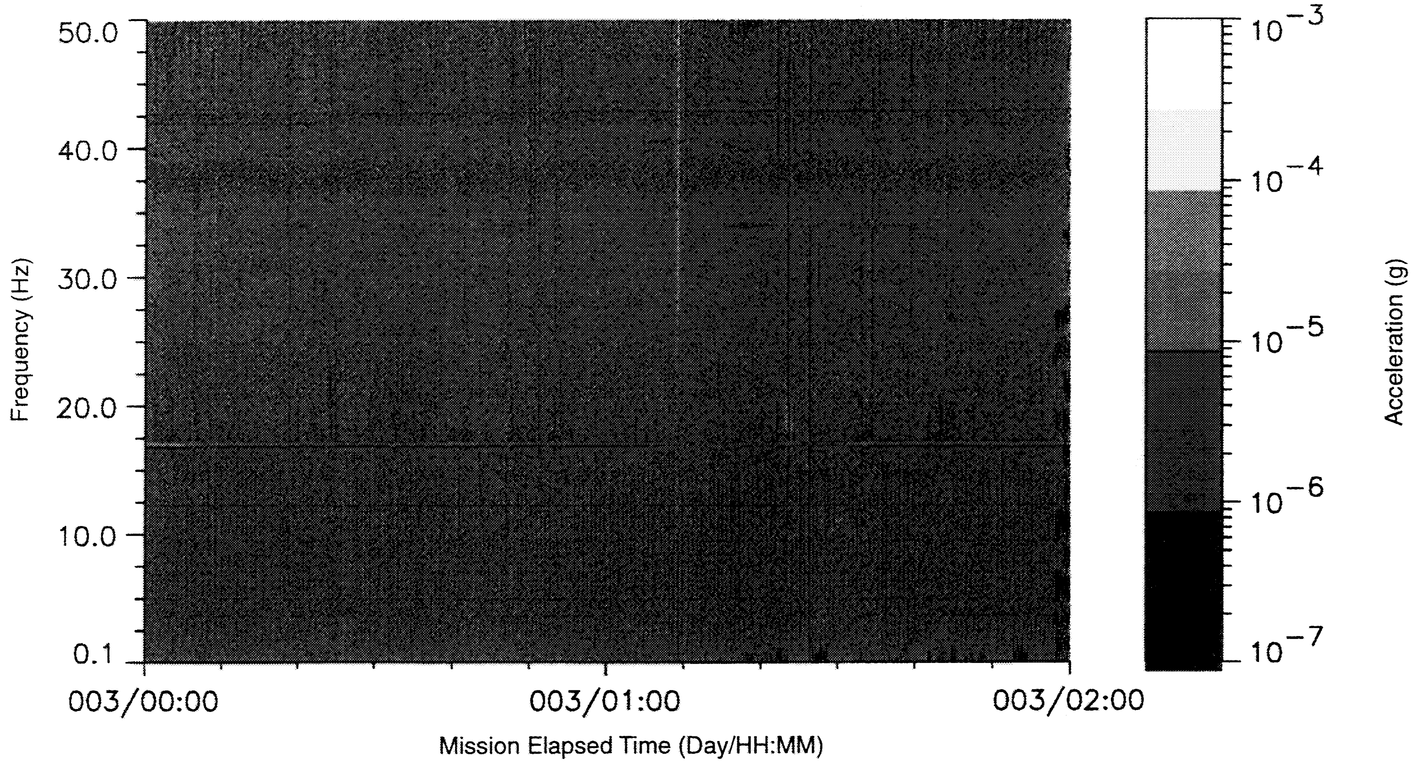

Figure C-34 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

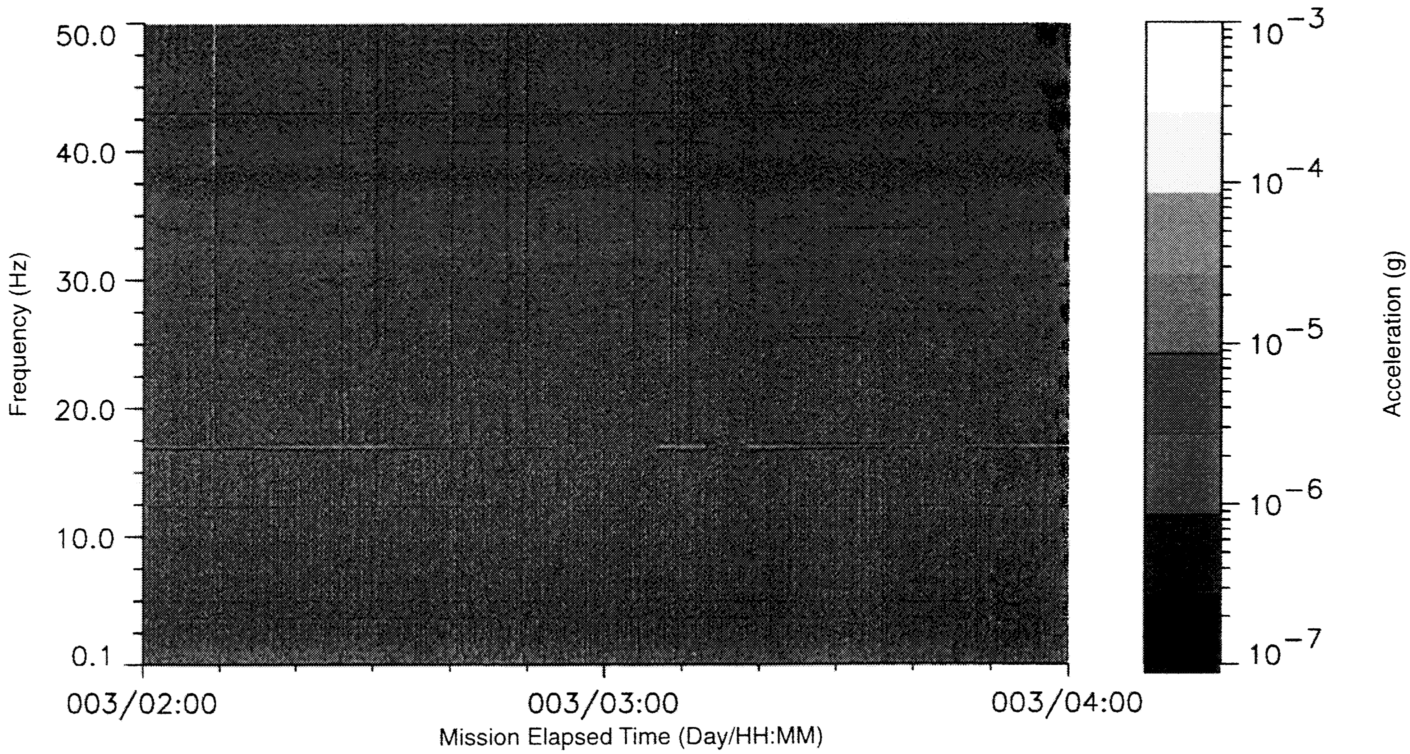

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Figure C-35 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

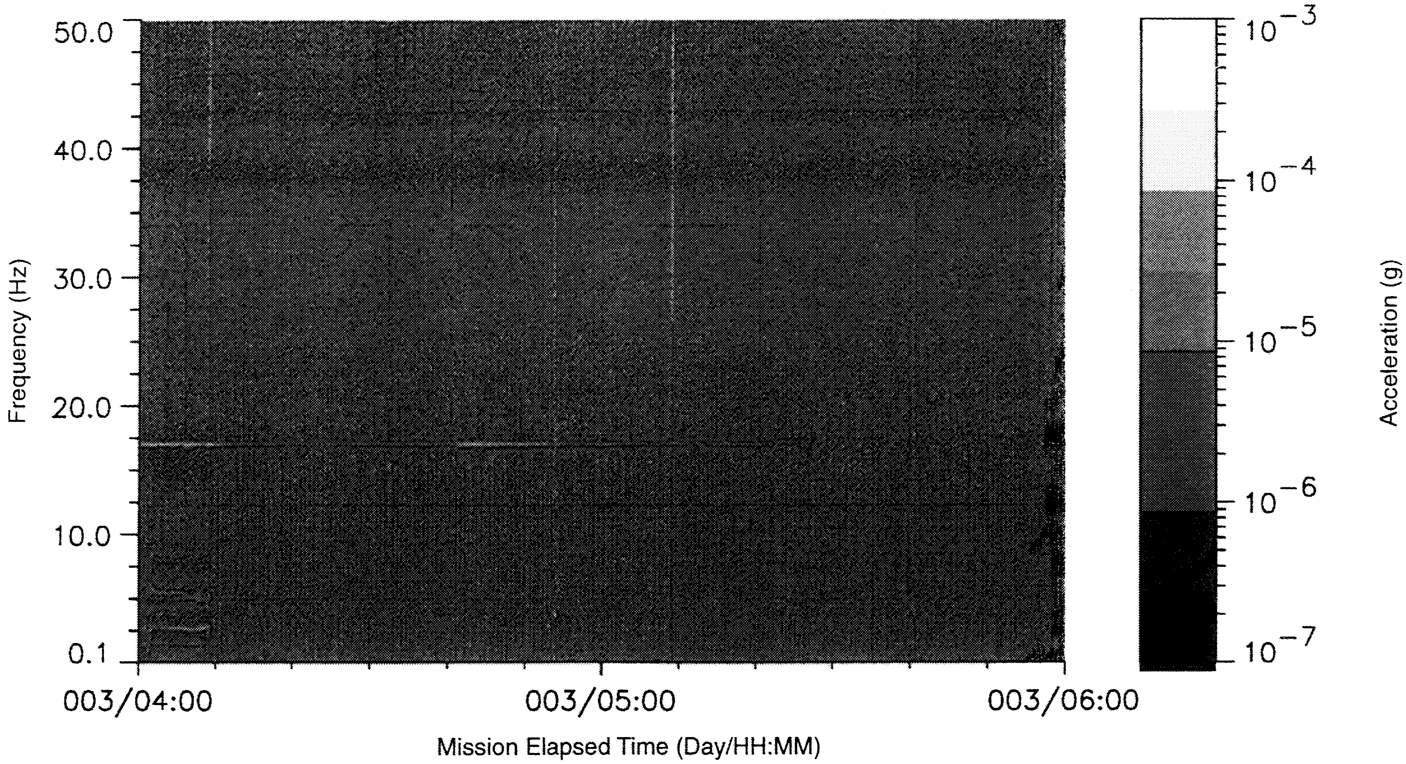

Figure C-36 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

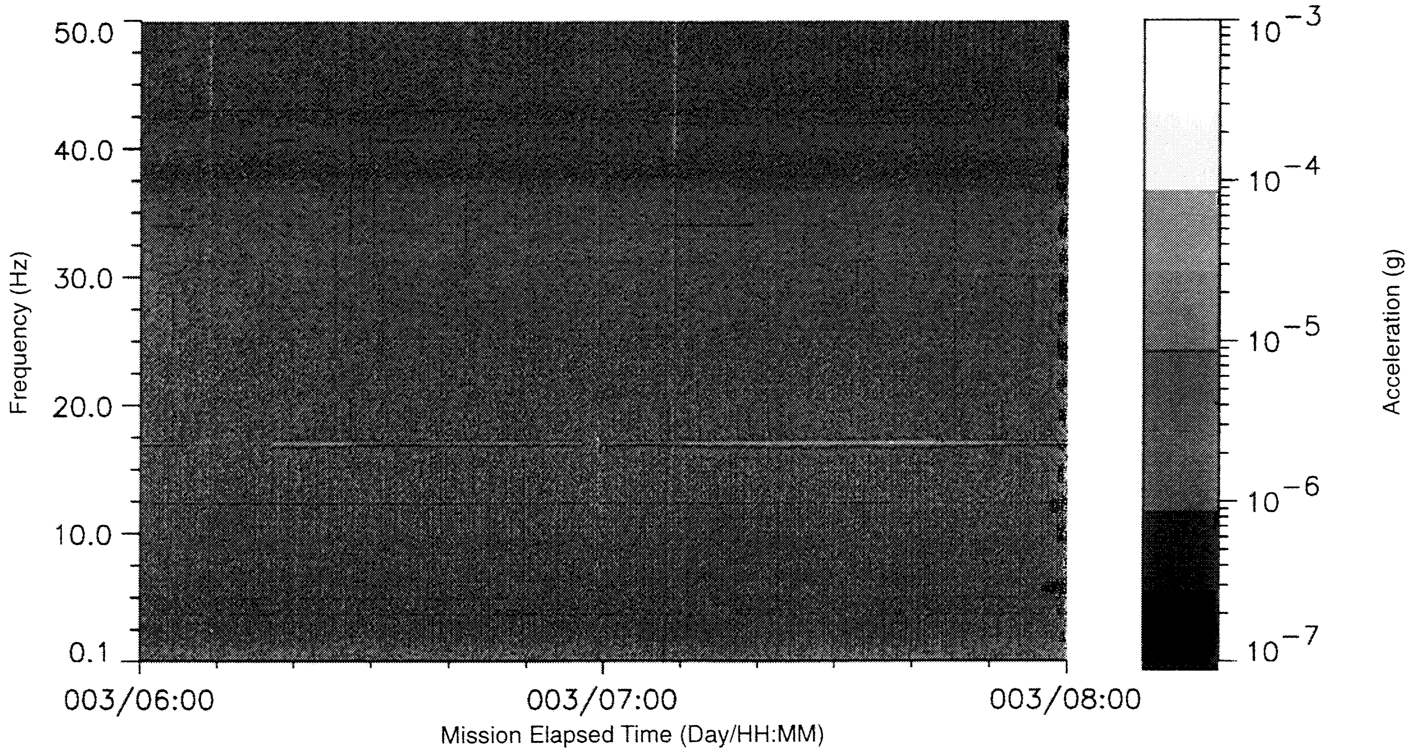

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Figure C-37 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

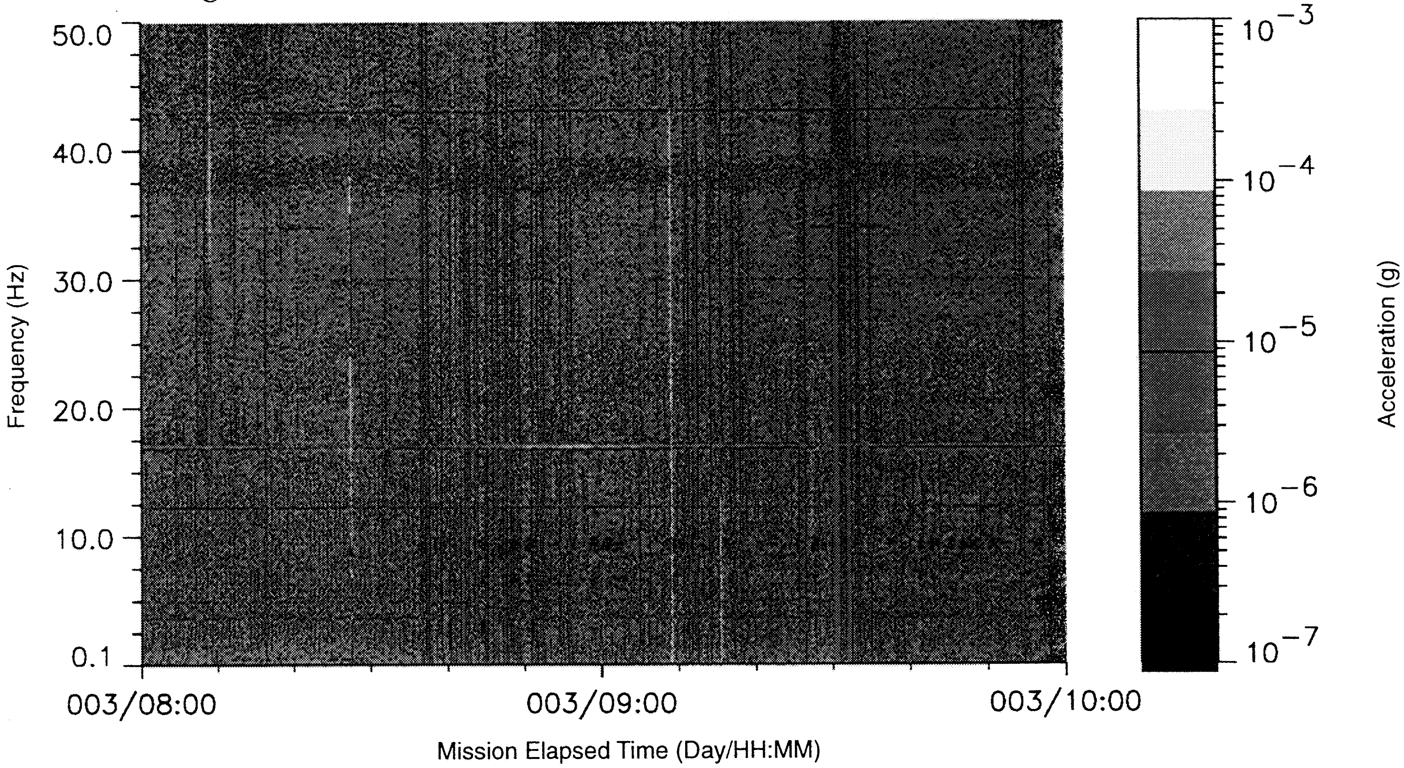

Figure C-38 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

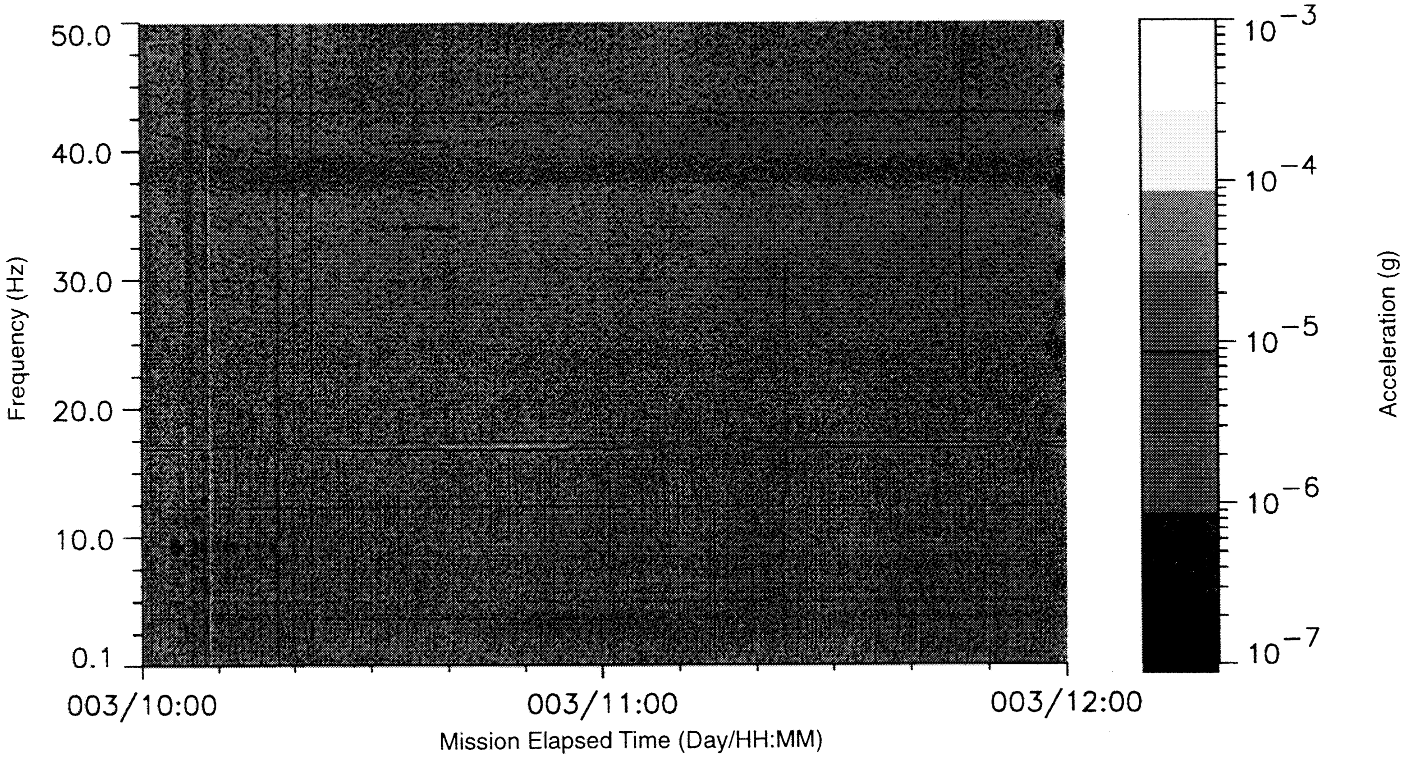

Figure C-39 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

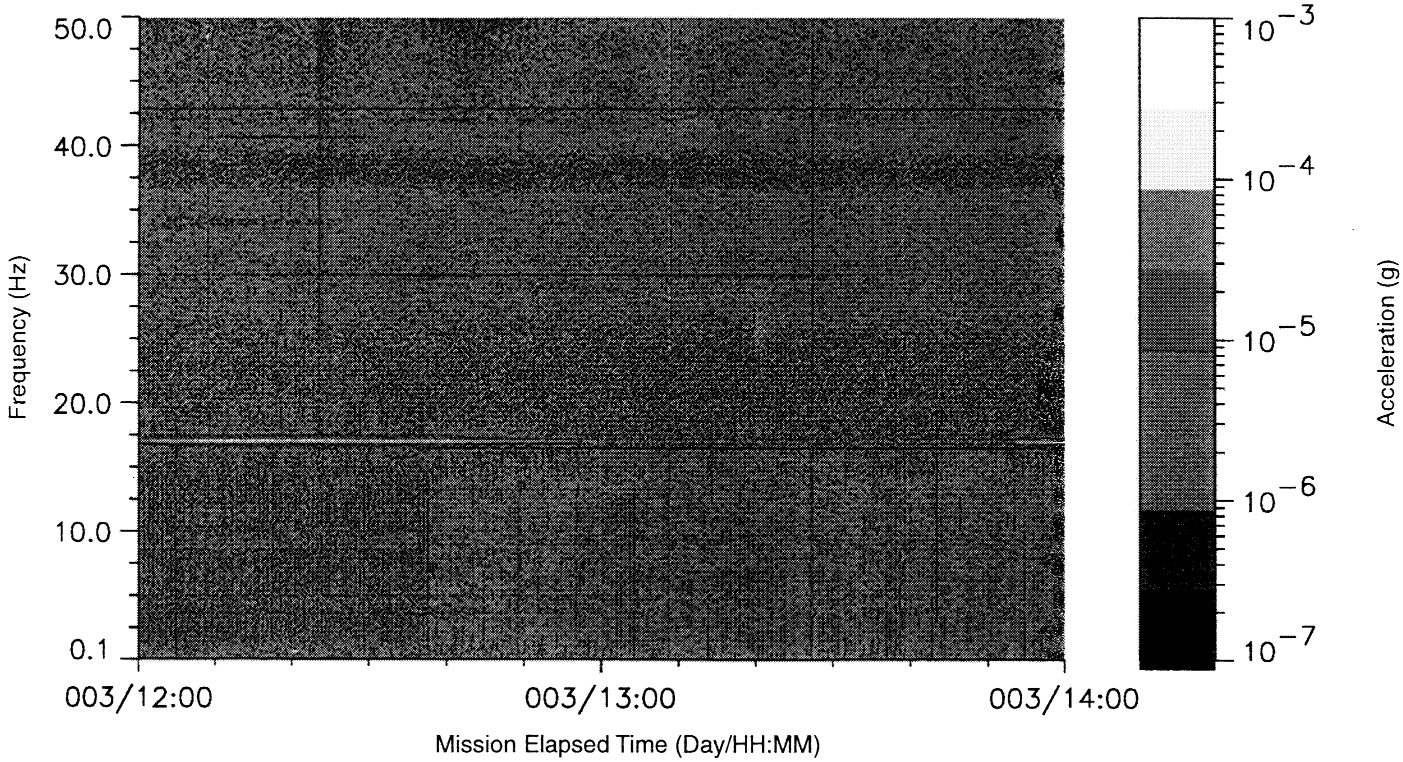

Figure C-40 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

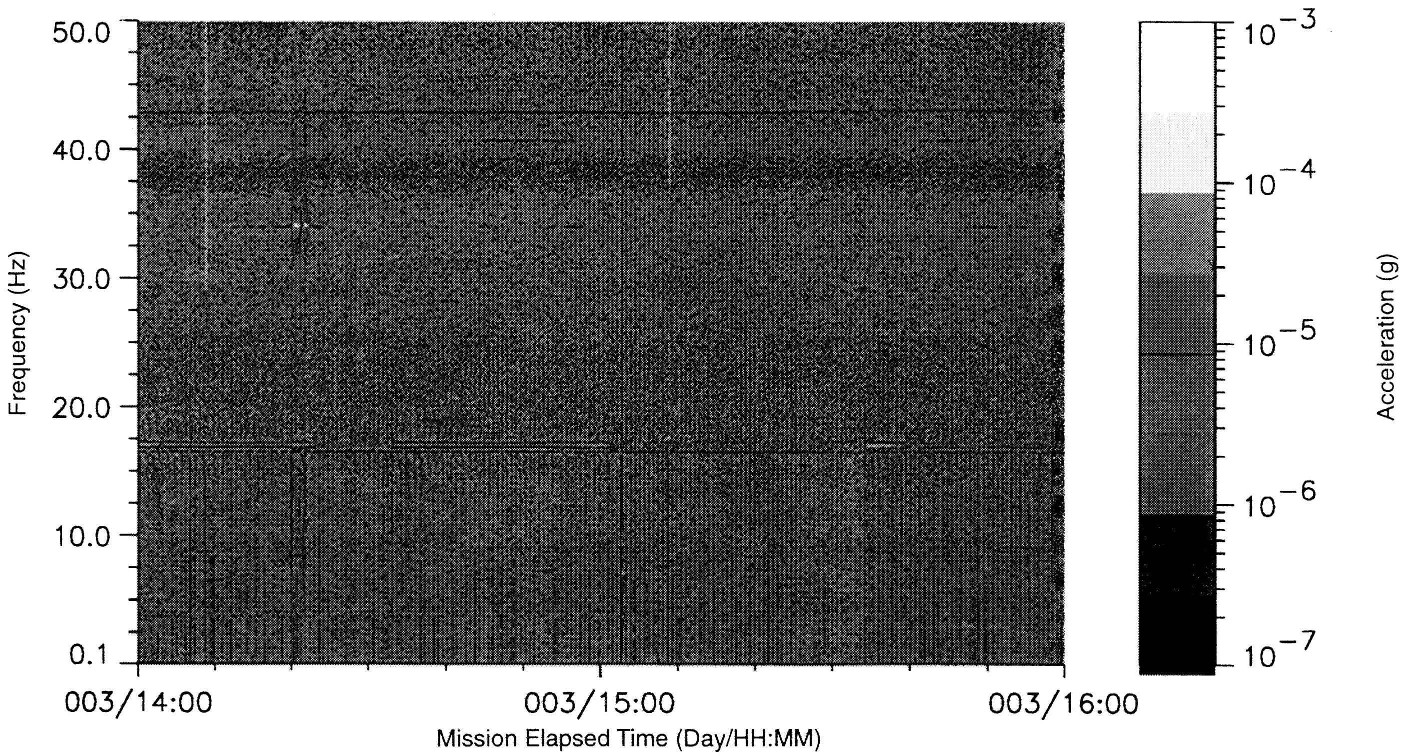

Figure C-41 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

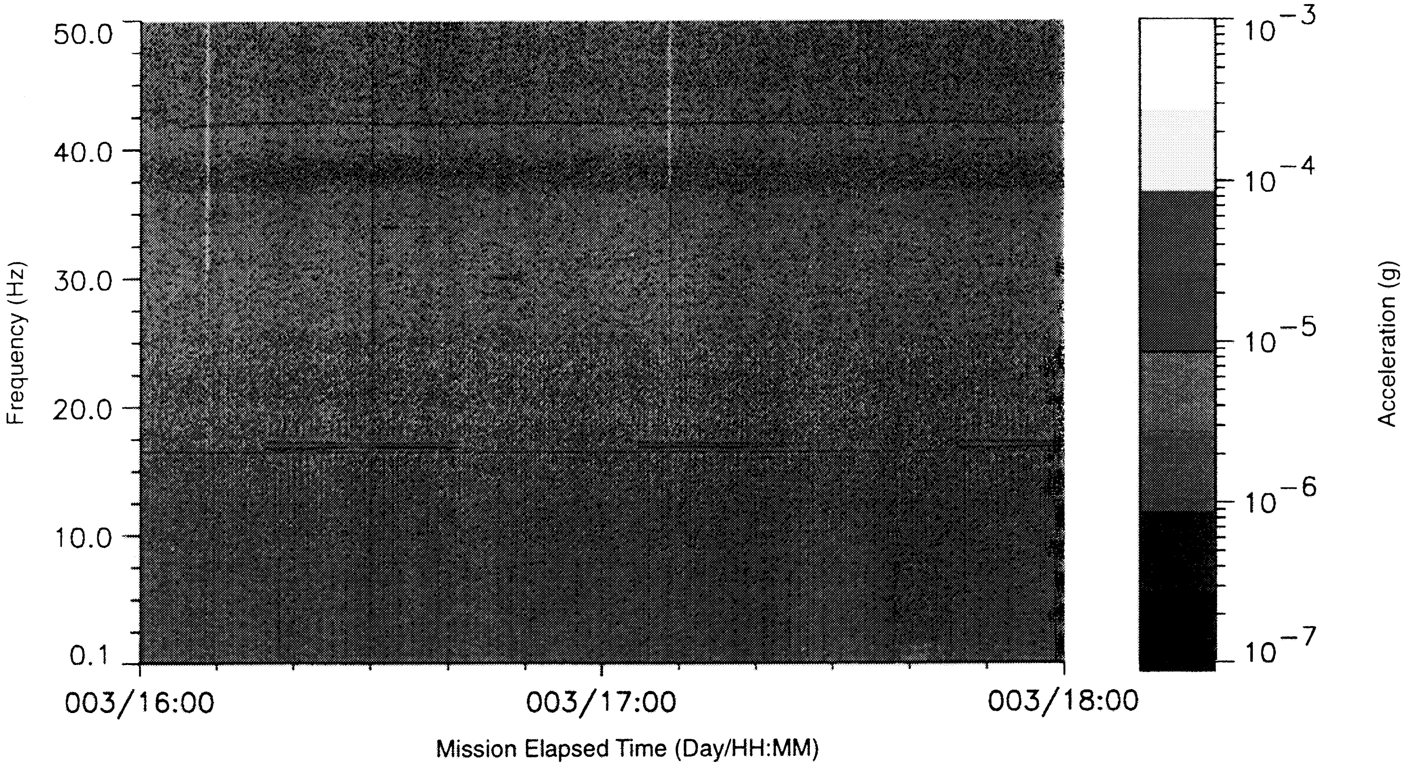

Figure C-42 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

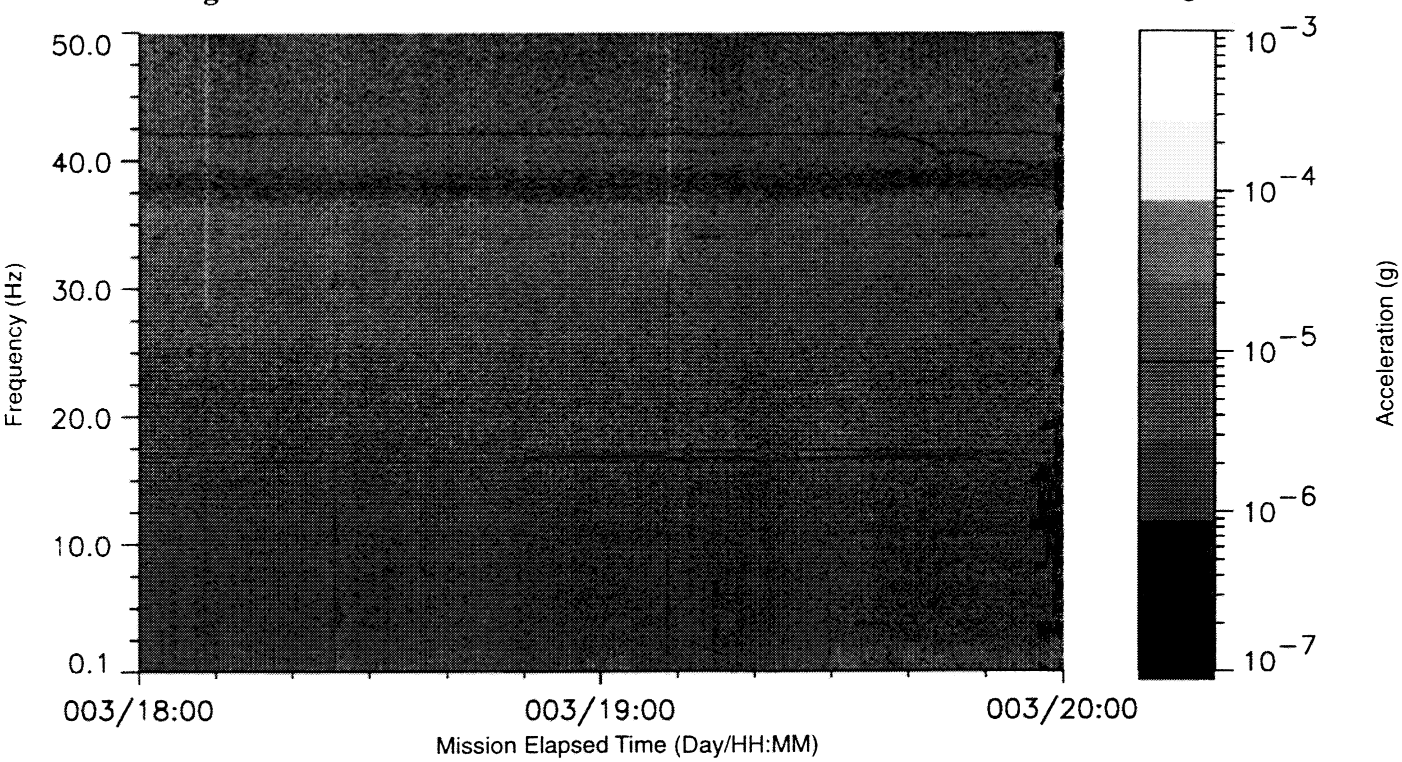

Figure C-43 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

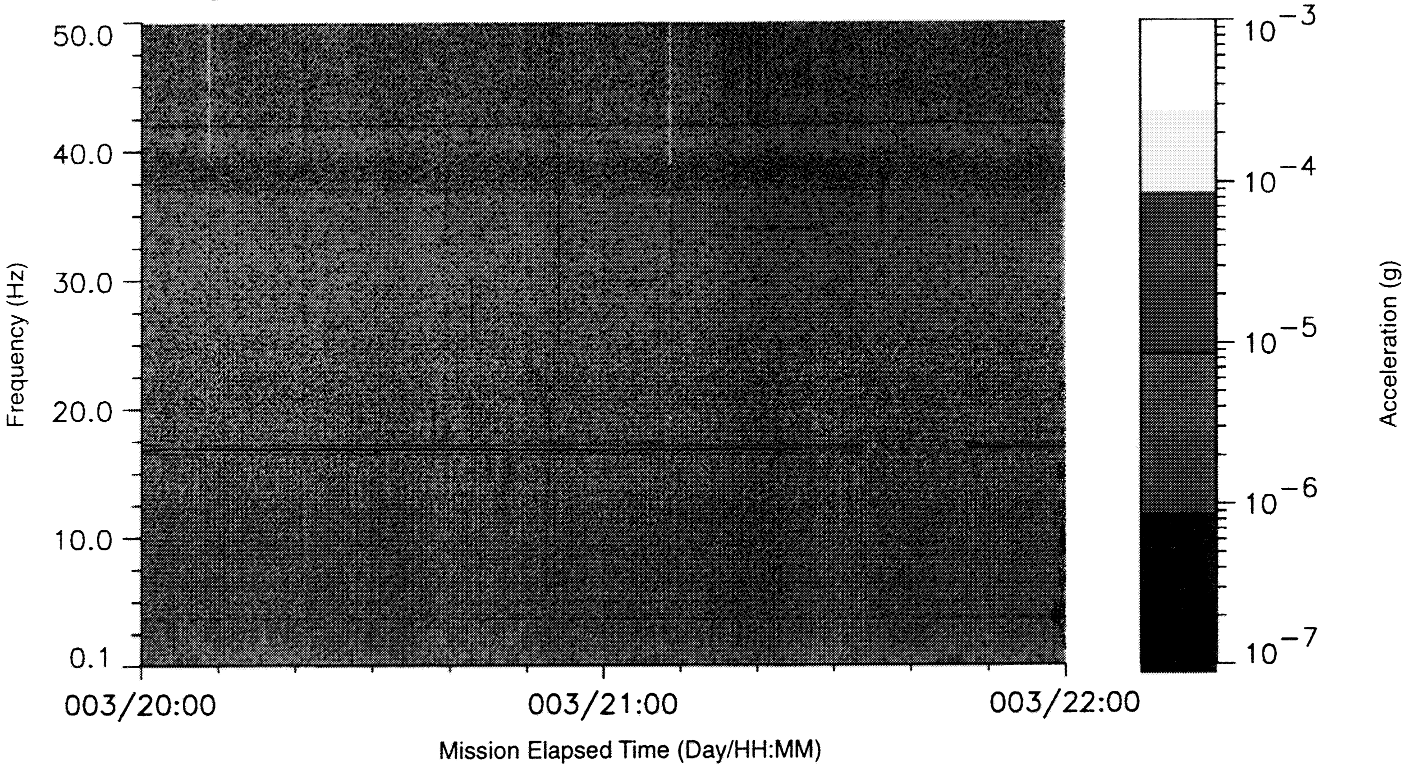

Figure C-44 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

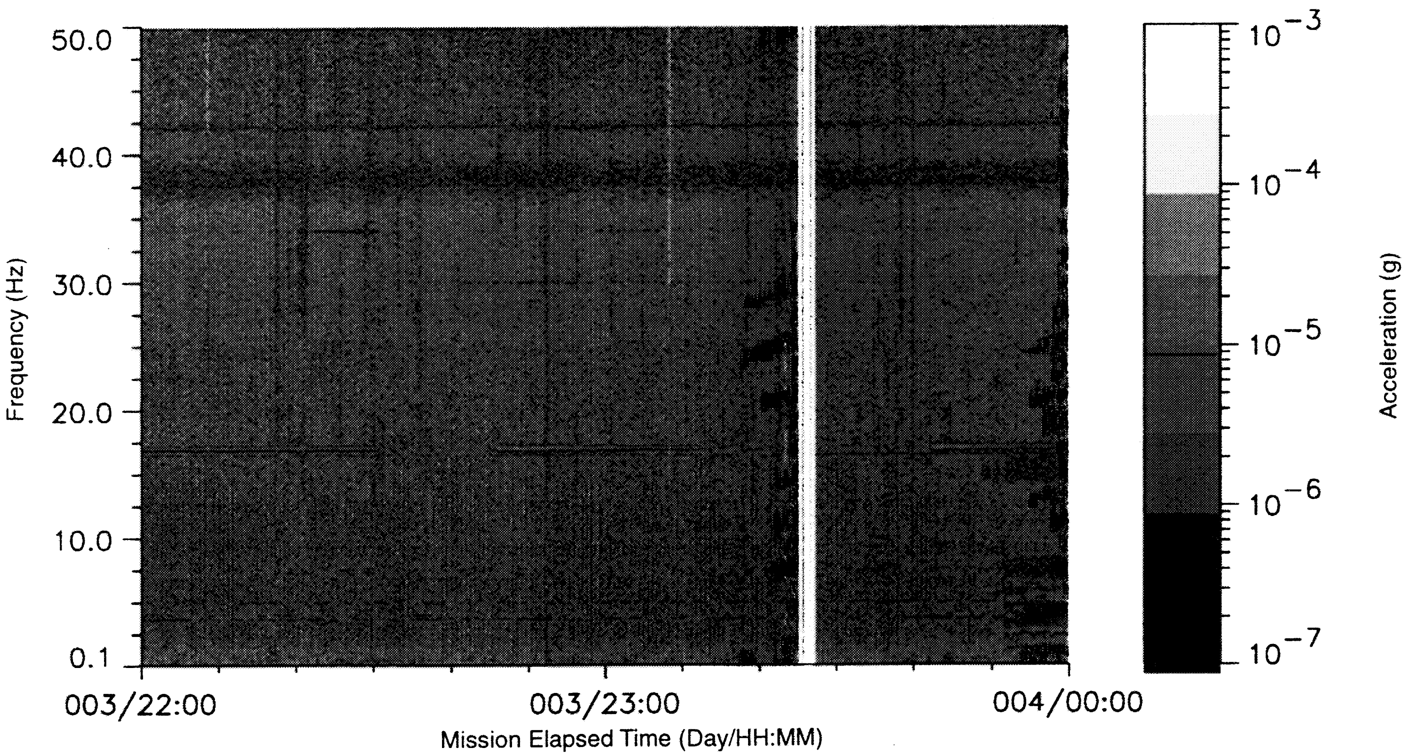

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Figure C-45 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

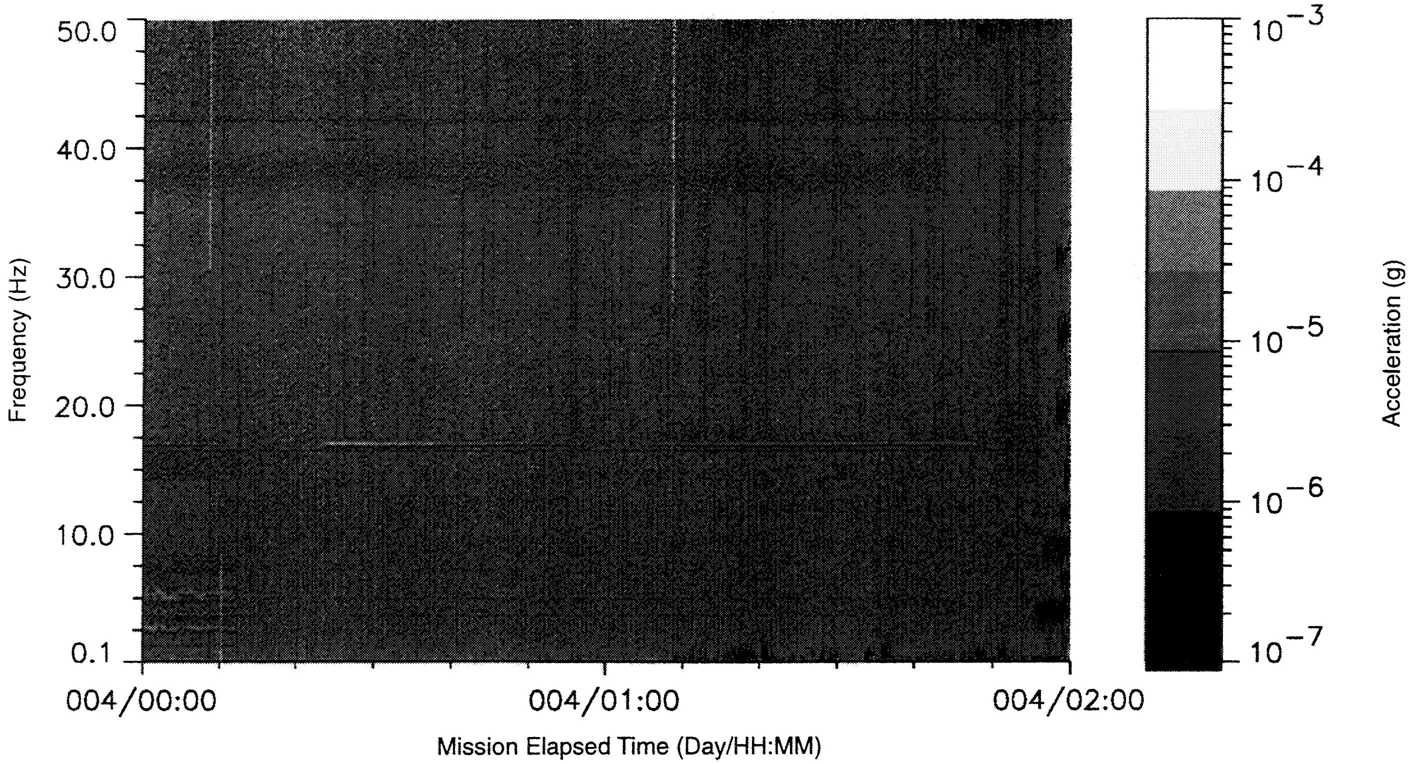

Figure C-46 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

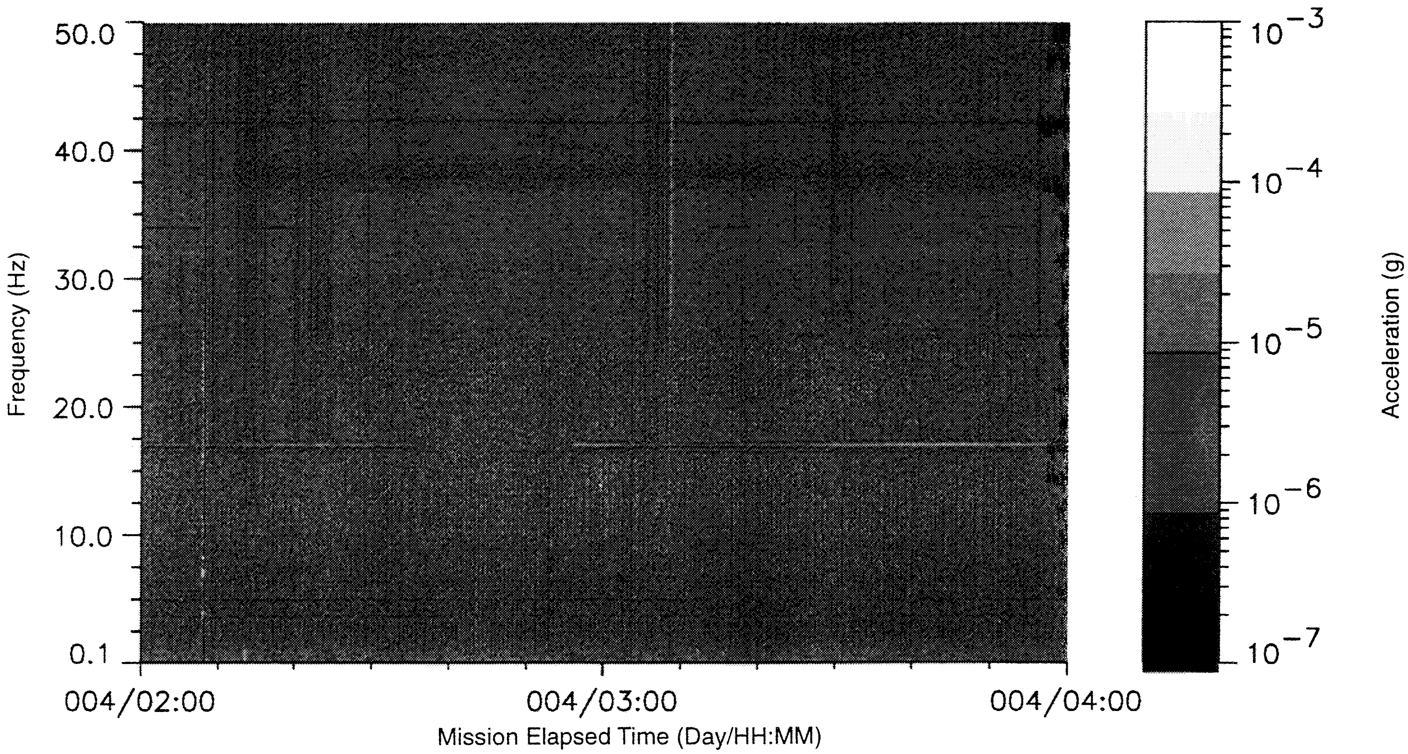

Figure C-47 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

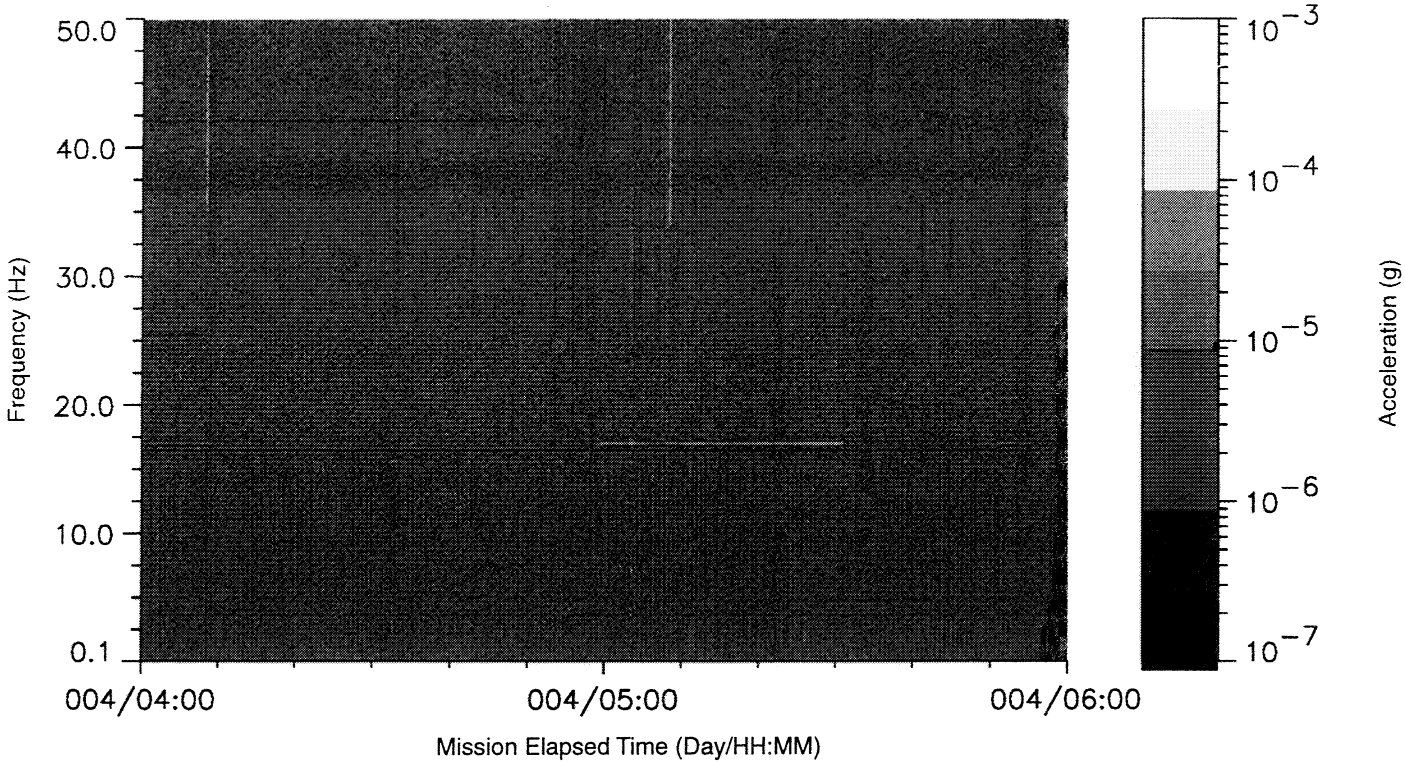

Figure C-48 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

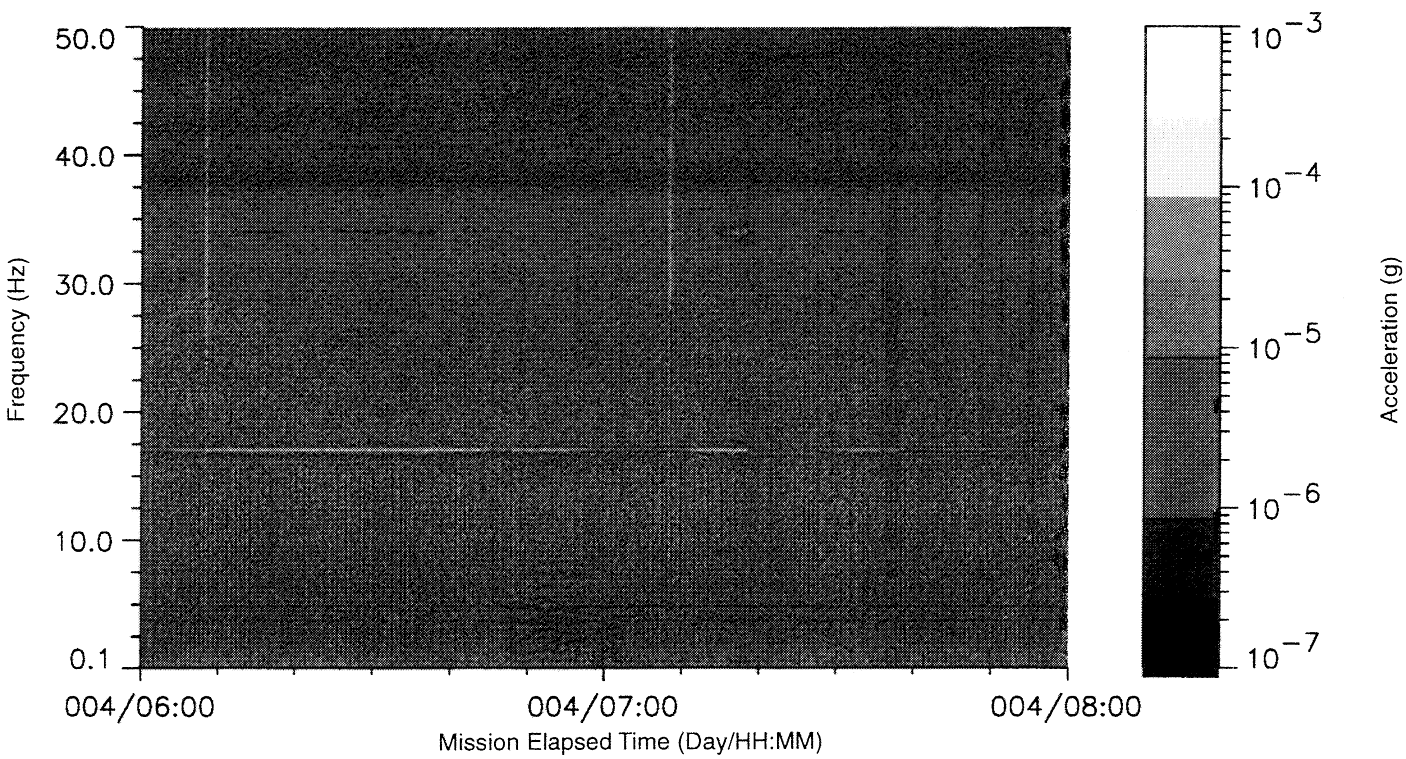

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Figure C-49 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

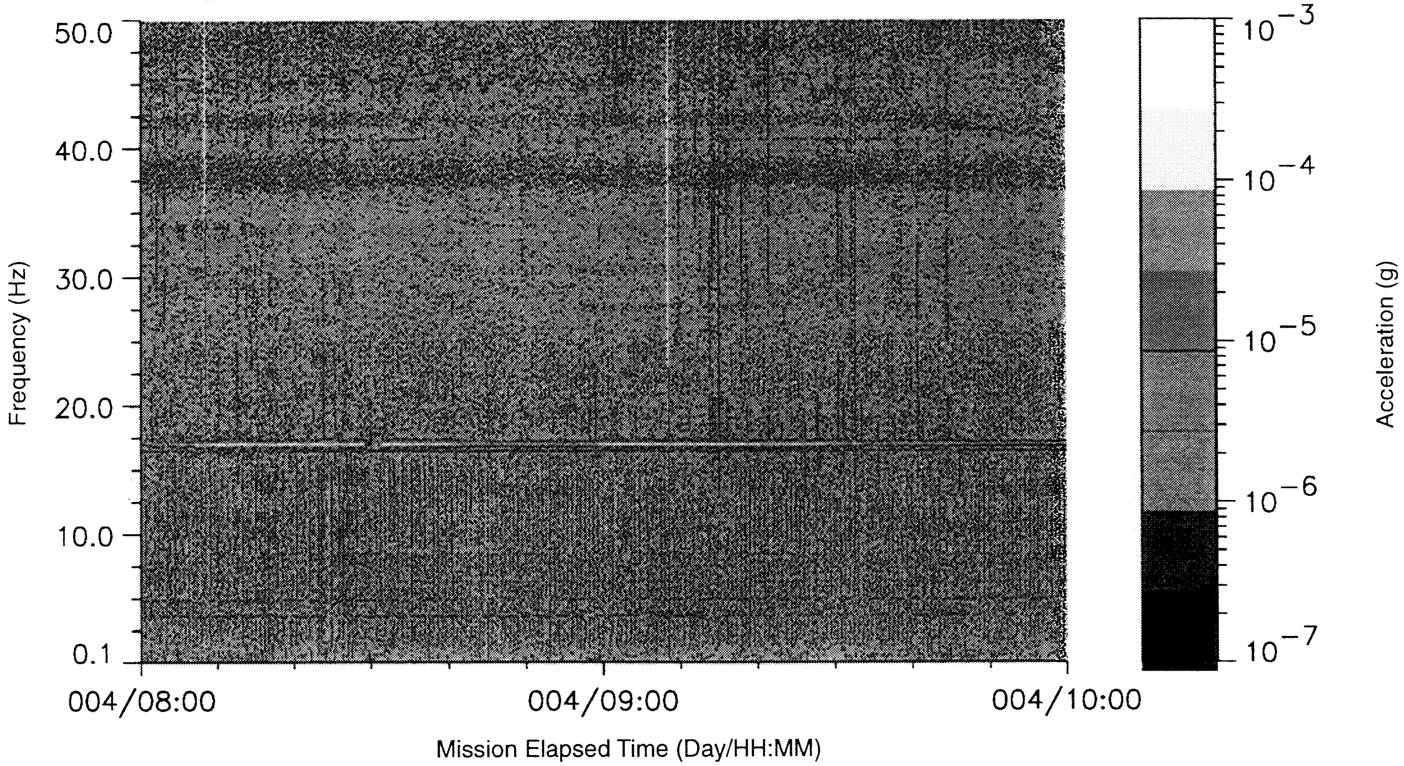

Figure C-50 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

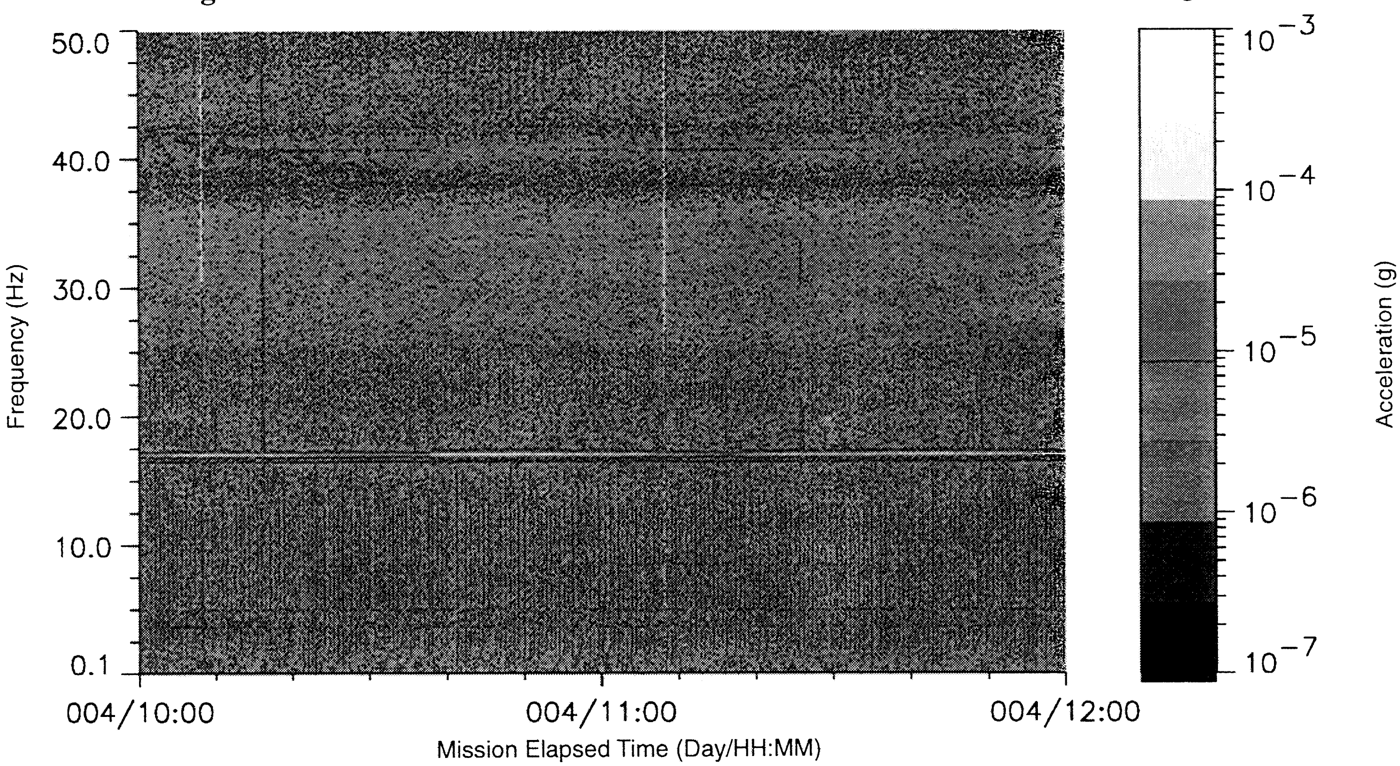

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Figure C-51 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

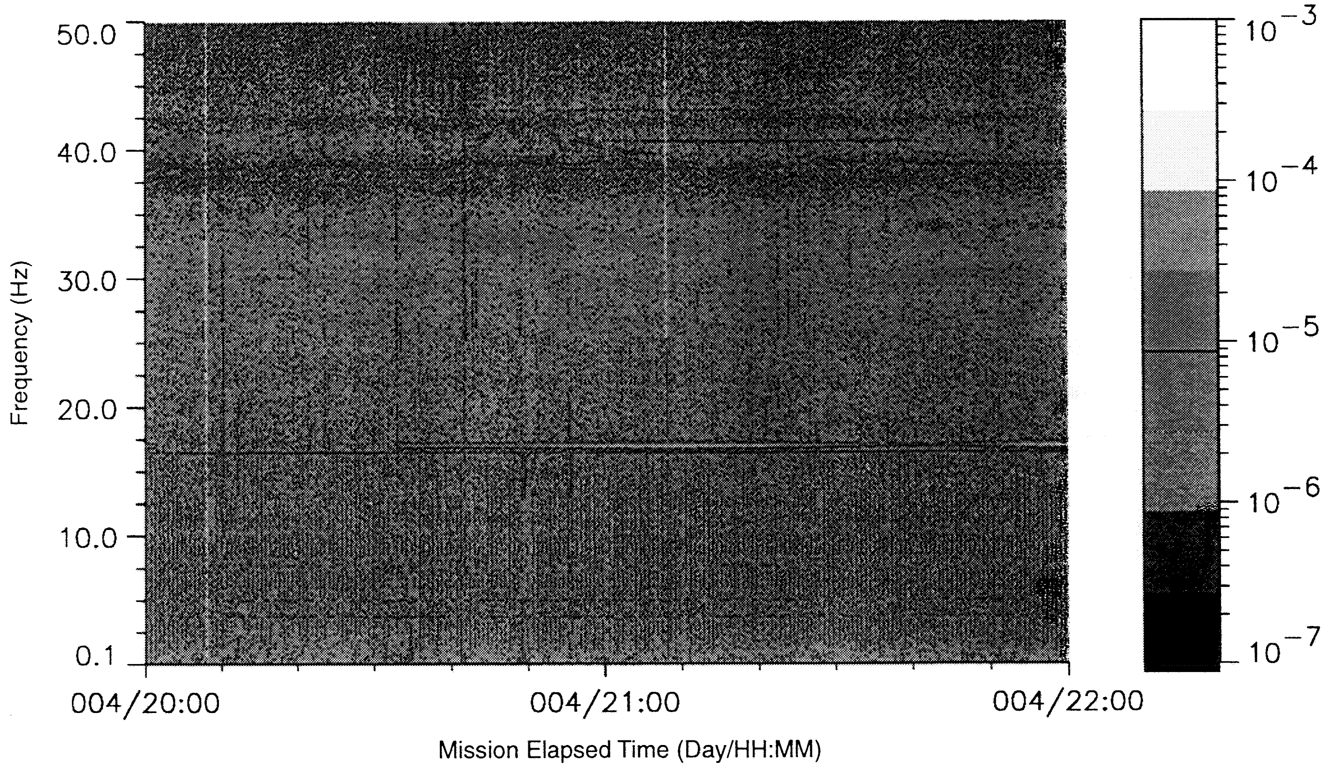


Figure C-52 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

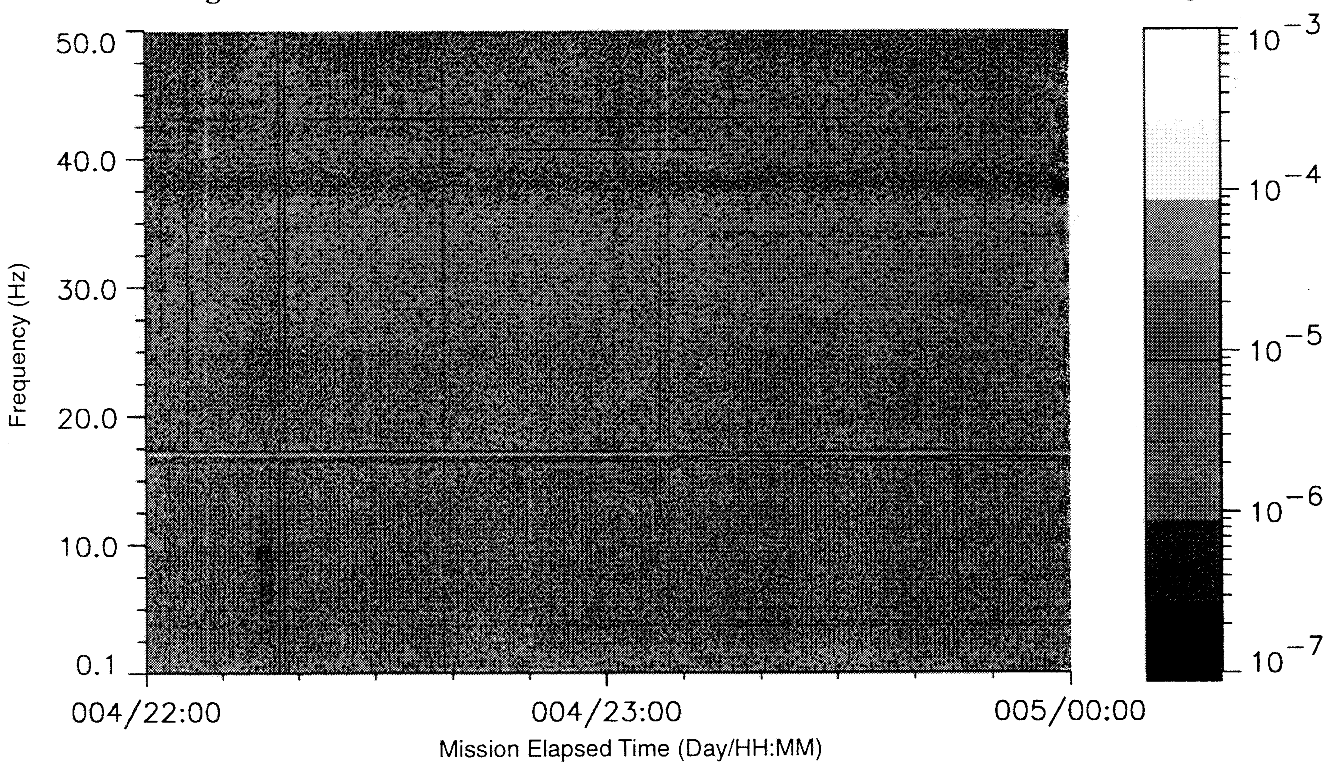
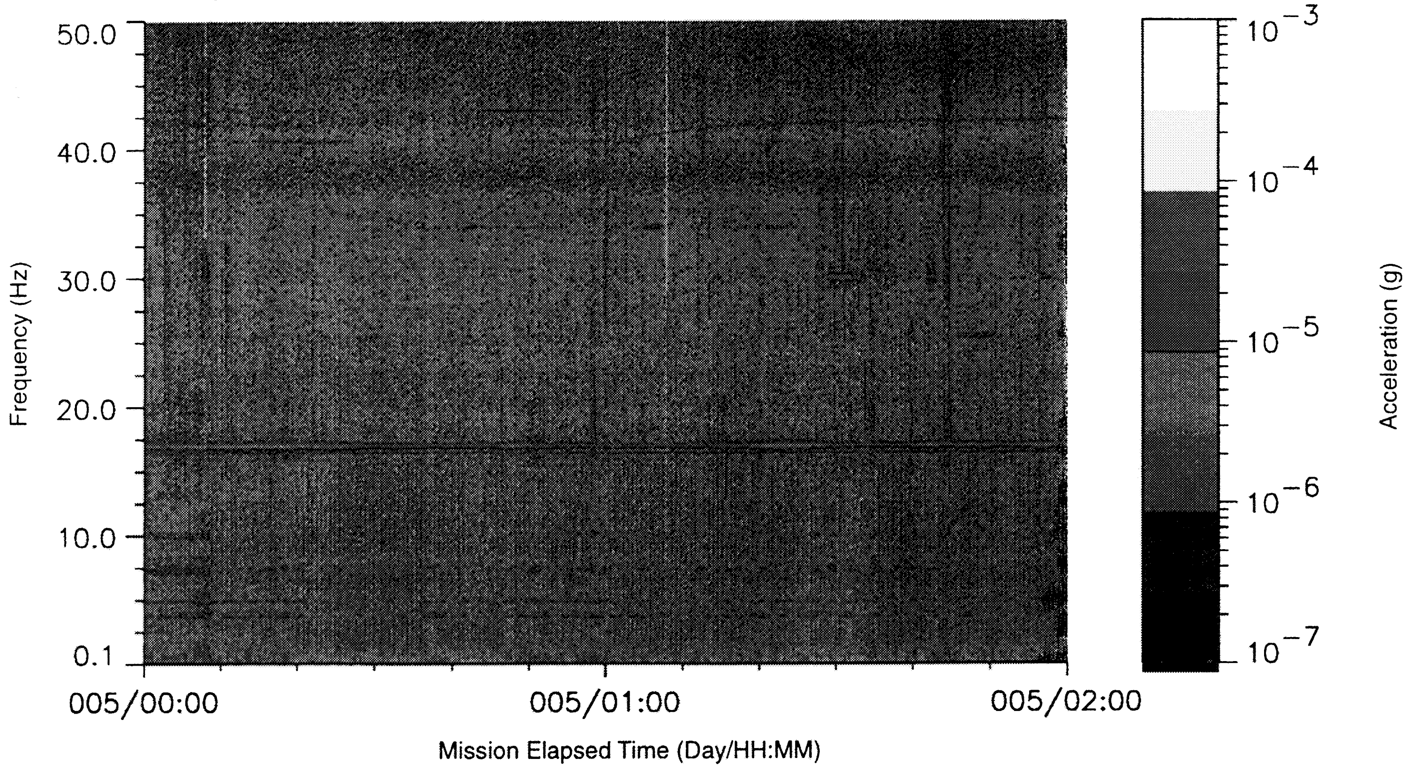


Figure C-53 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude



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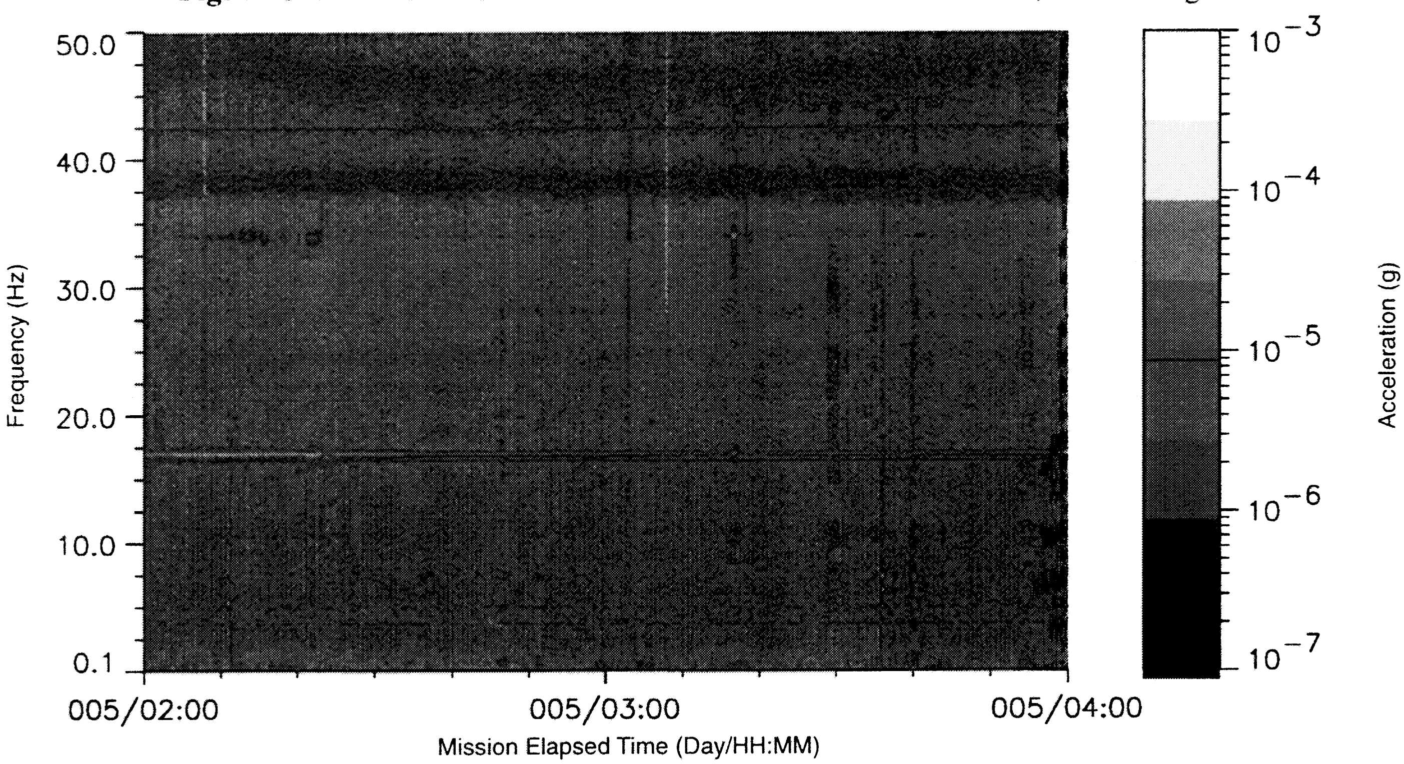

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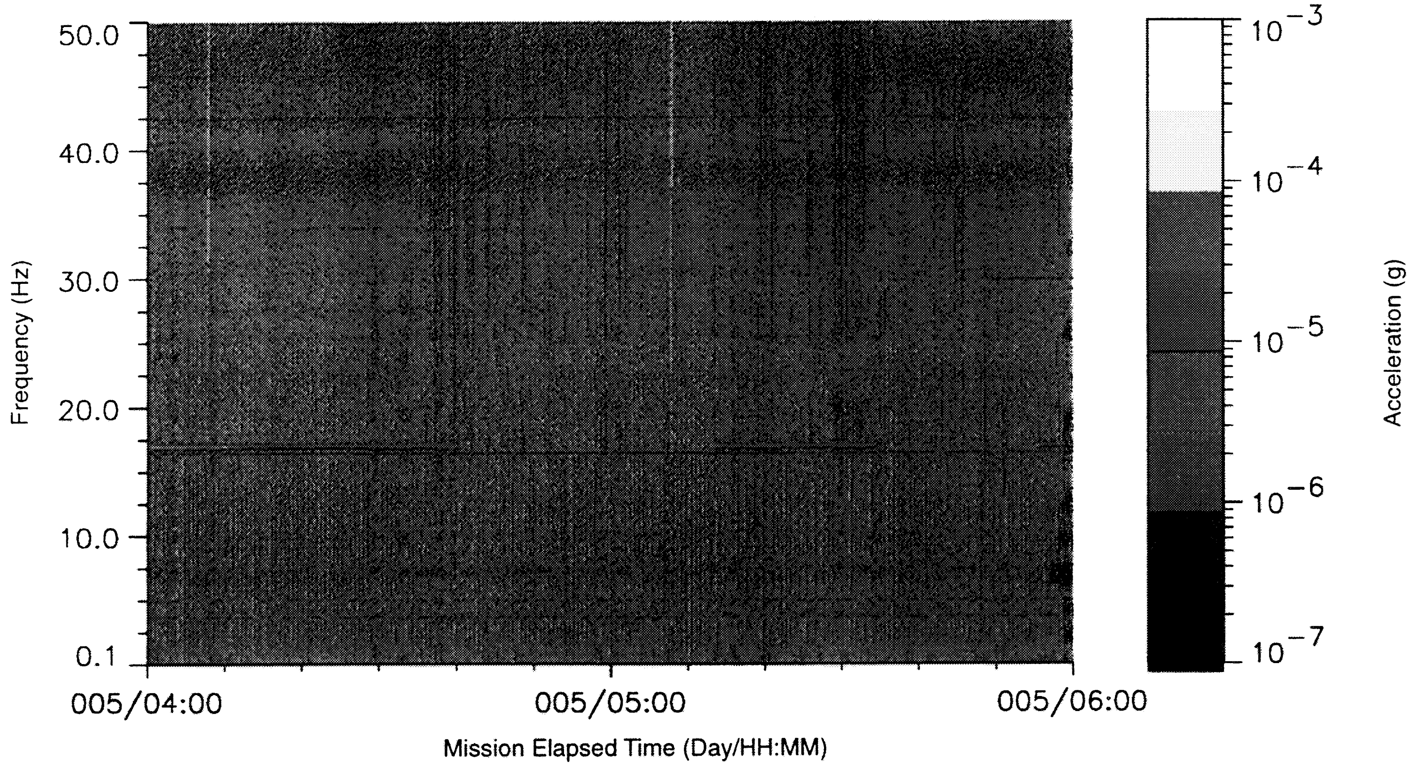

Figure C-56 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

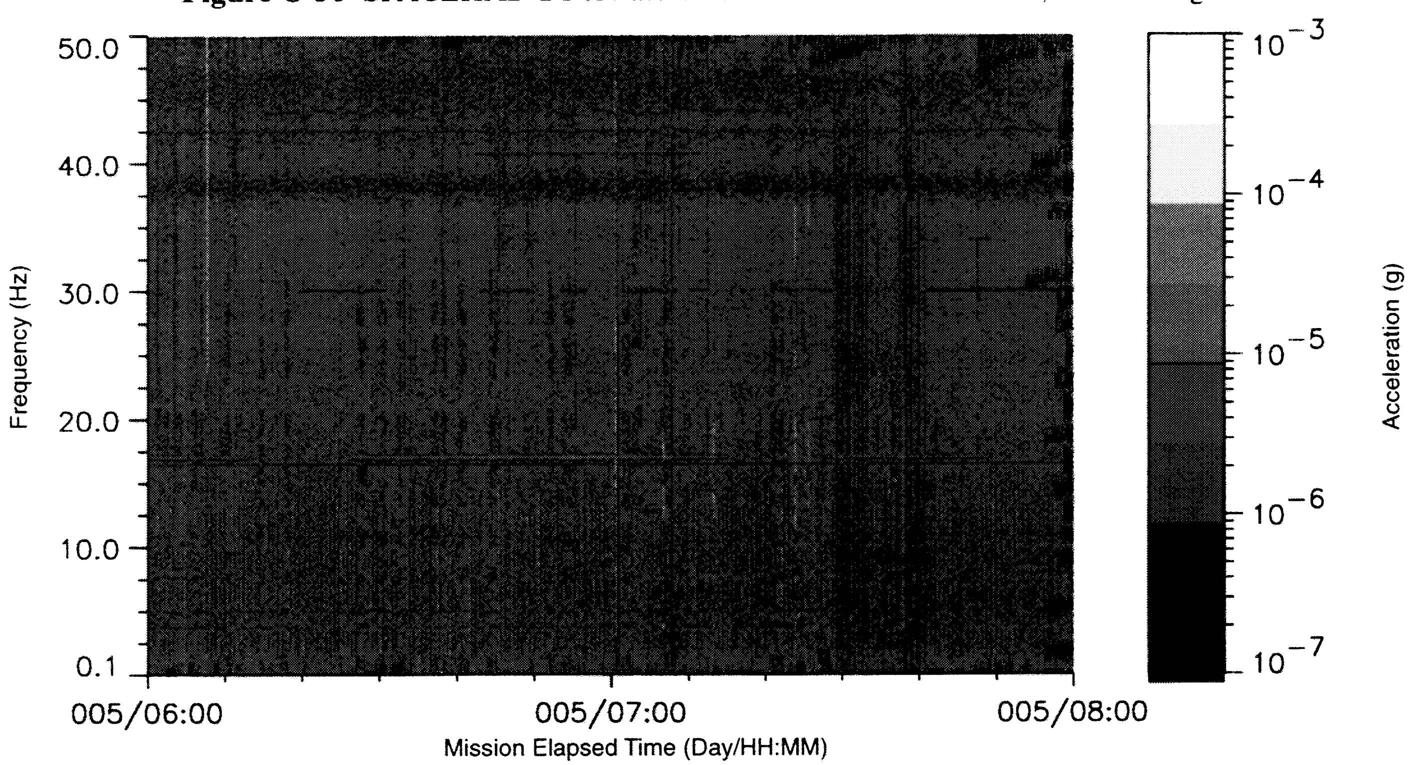

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Figure C-57 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

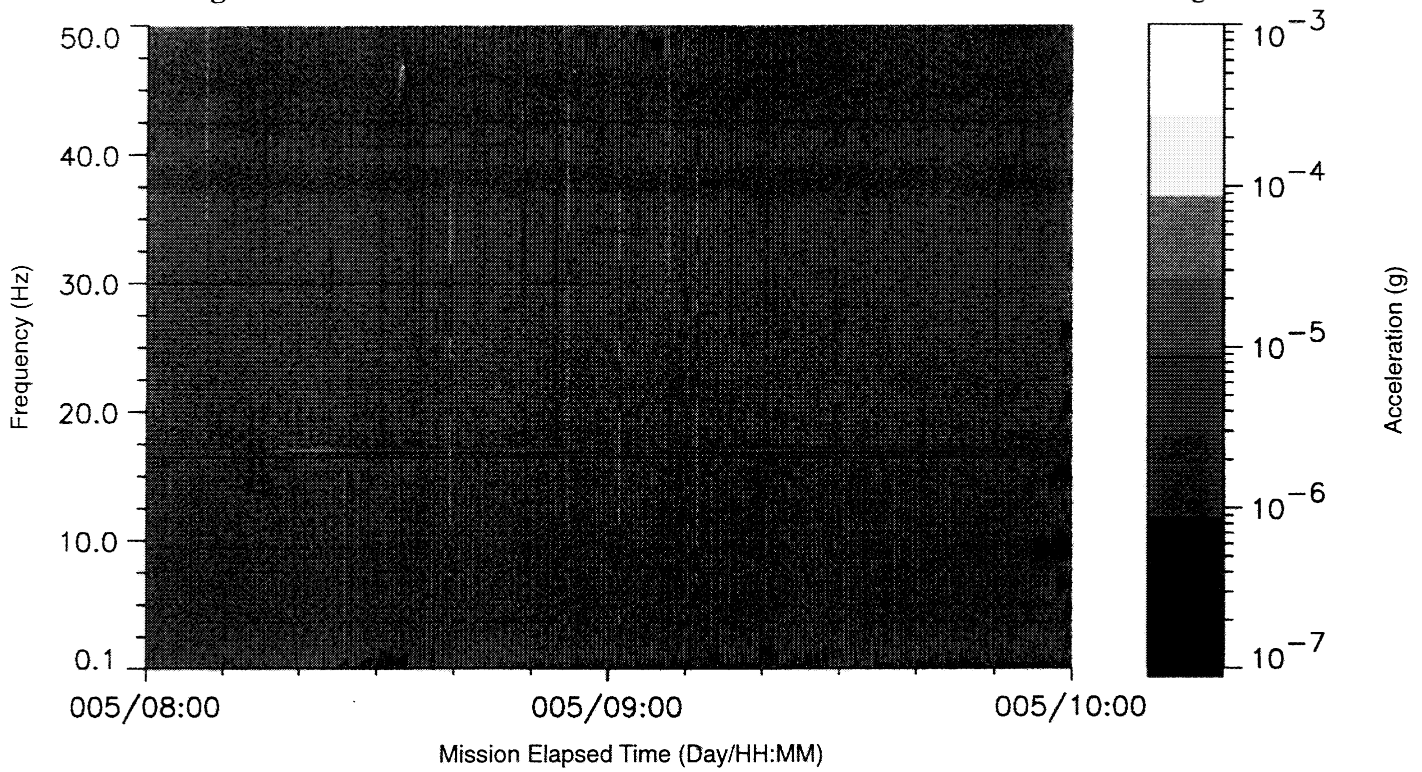

Figure C-58 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

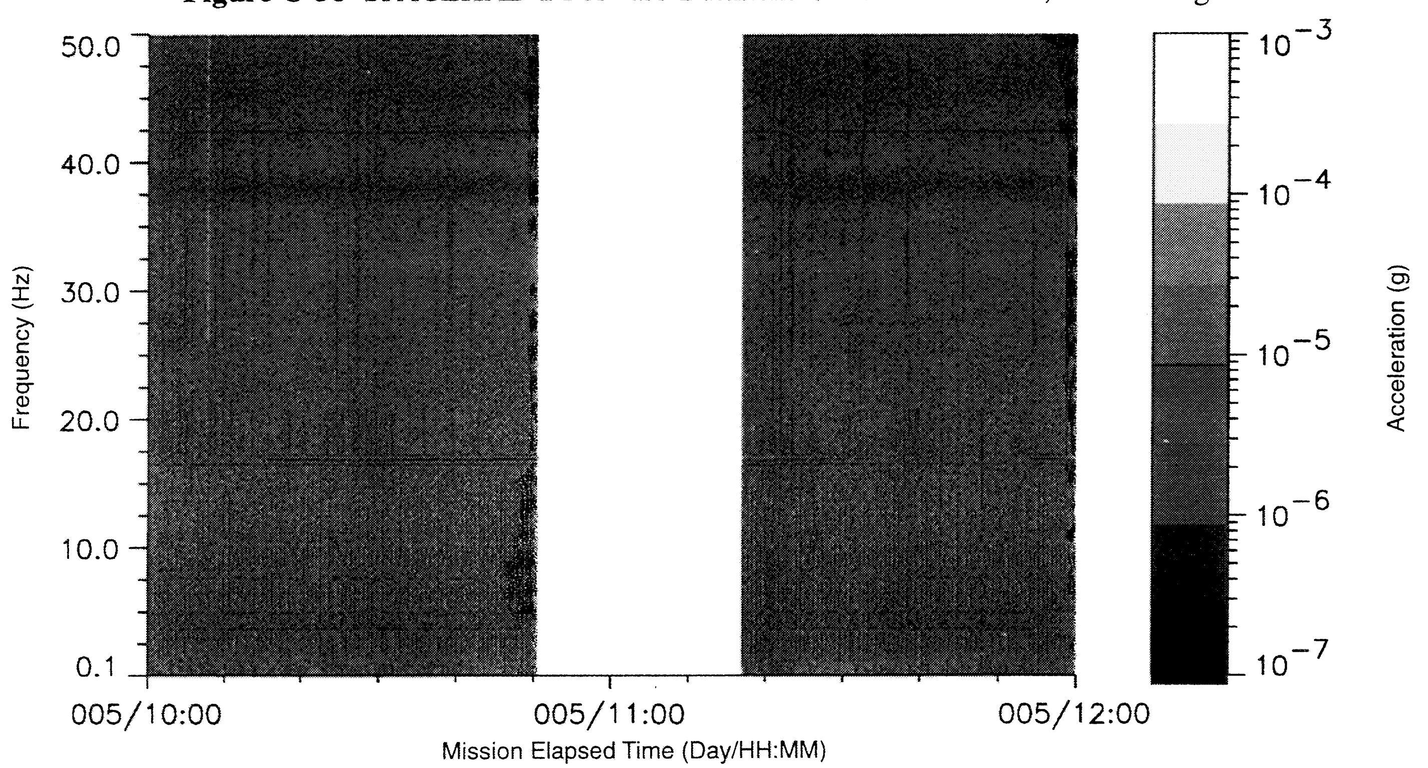

Figure C-59 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

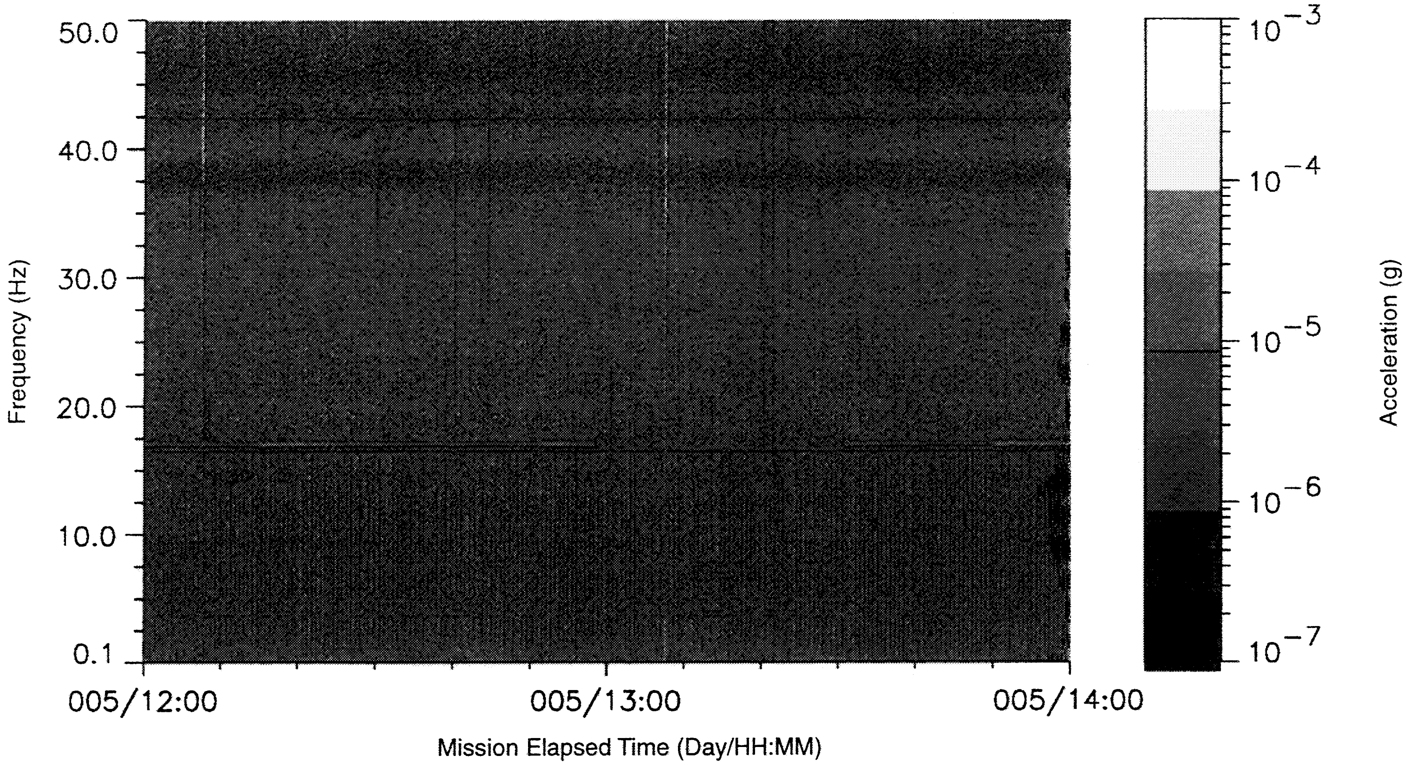

Figure C-60 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

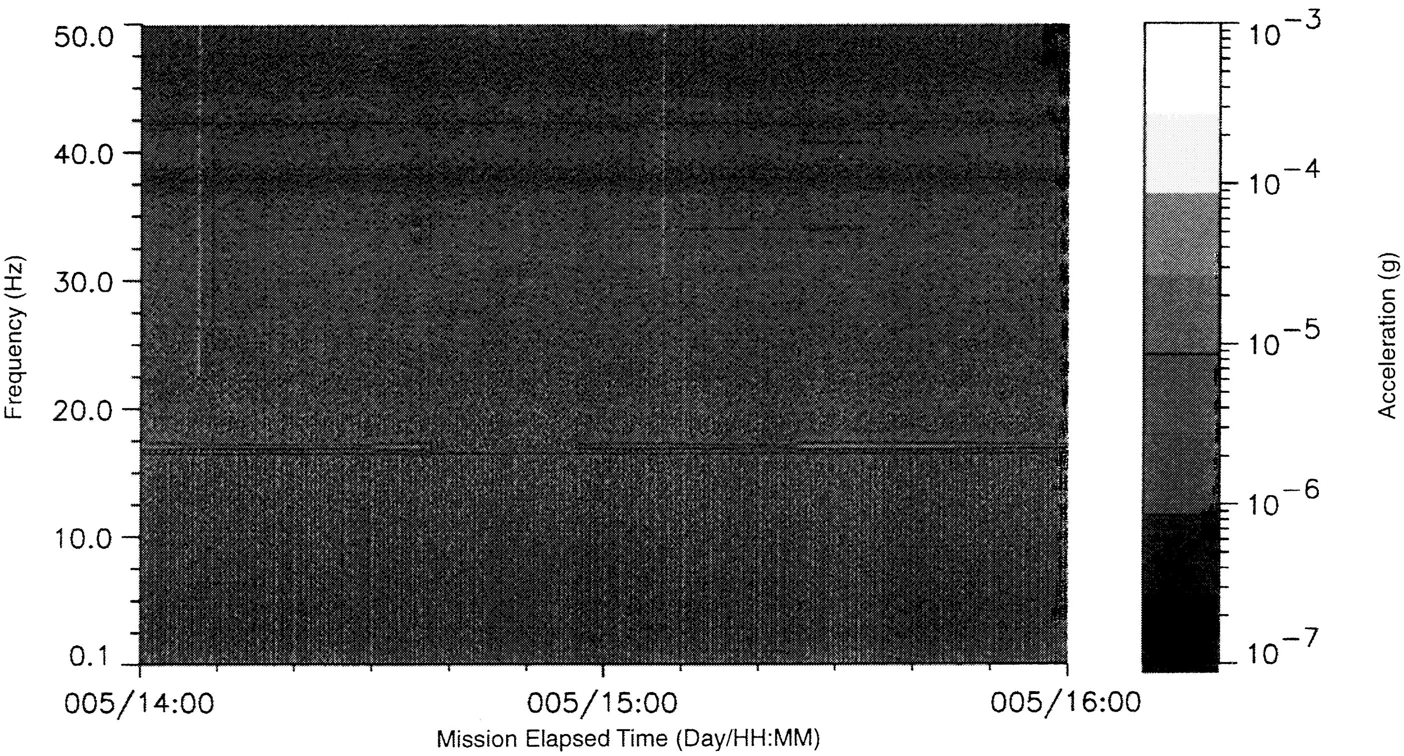

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Figure C-61 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

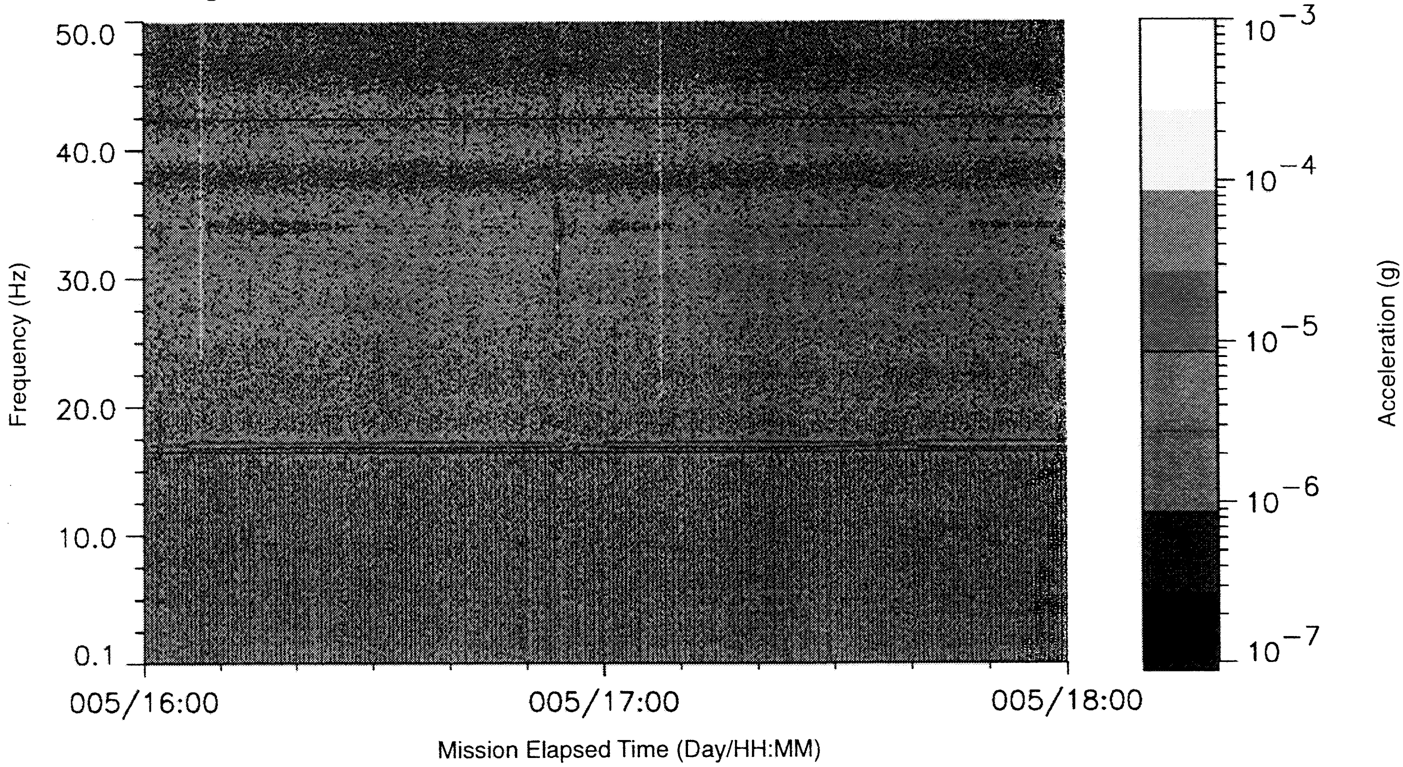
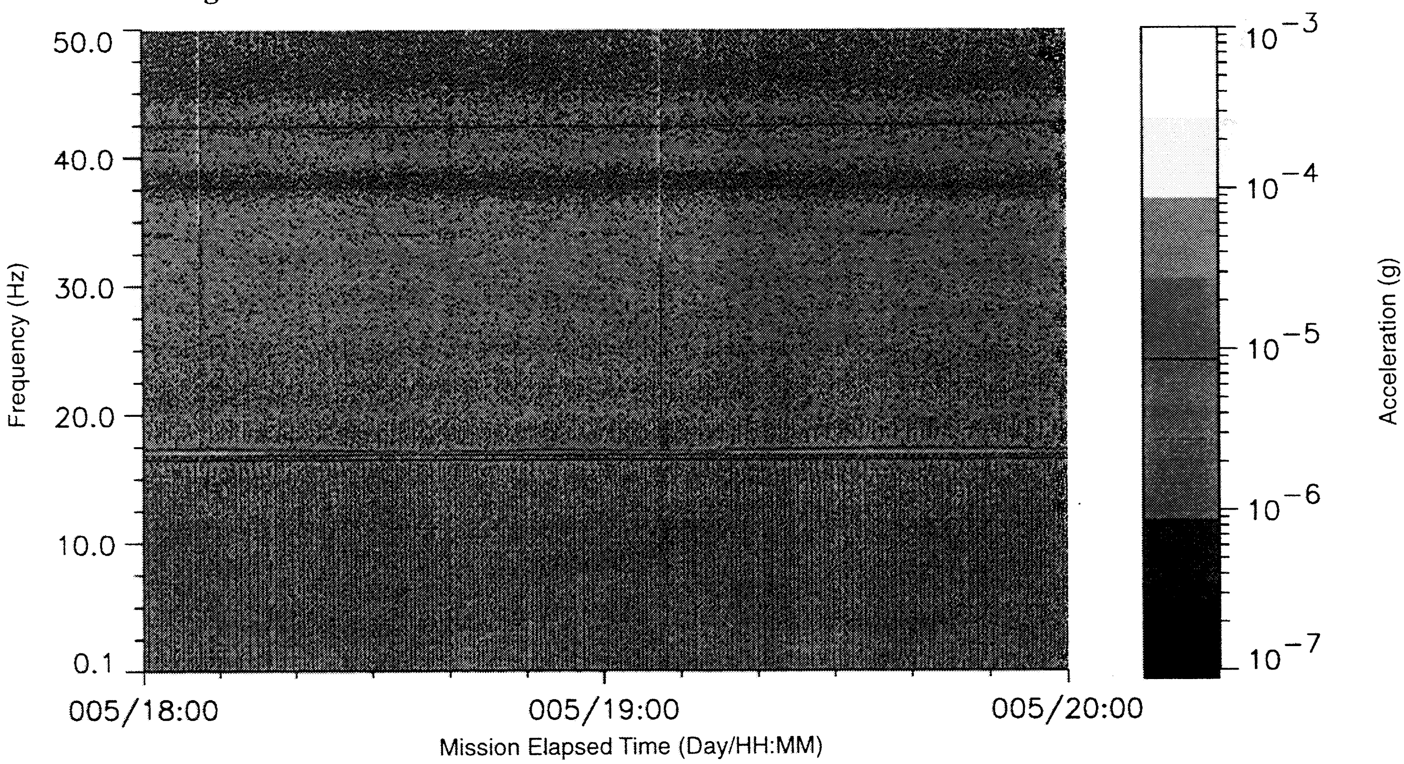


Figure C-62 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude



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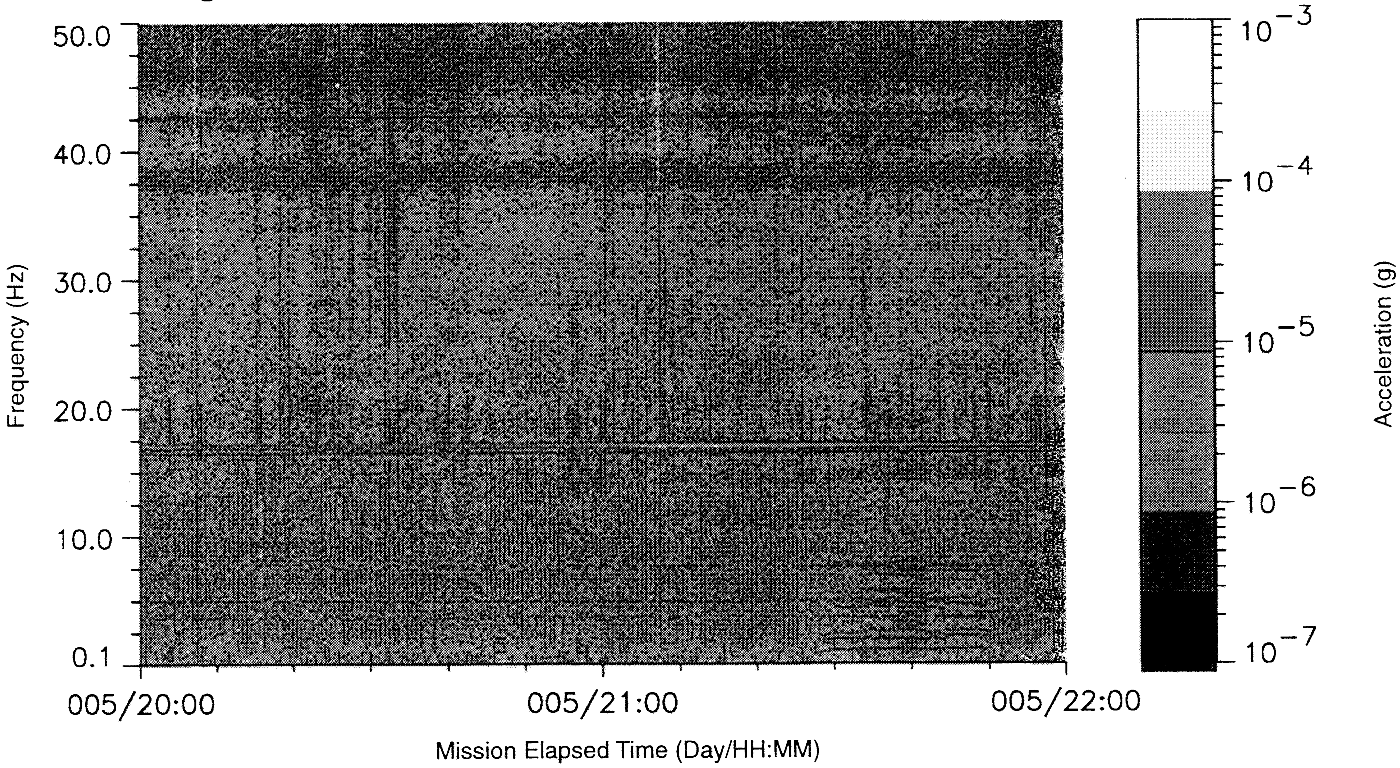

Figure C-64 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

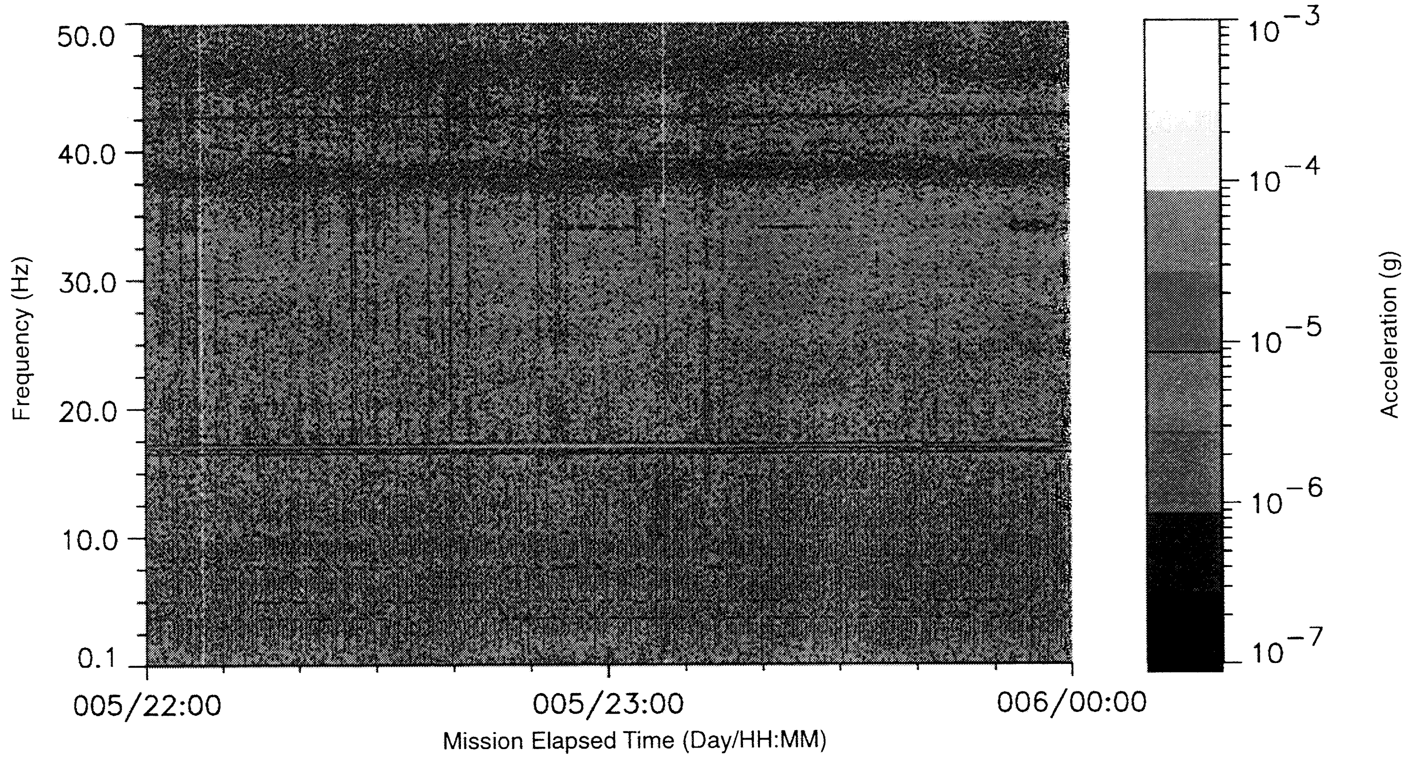

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Figure C-65 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

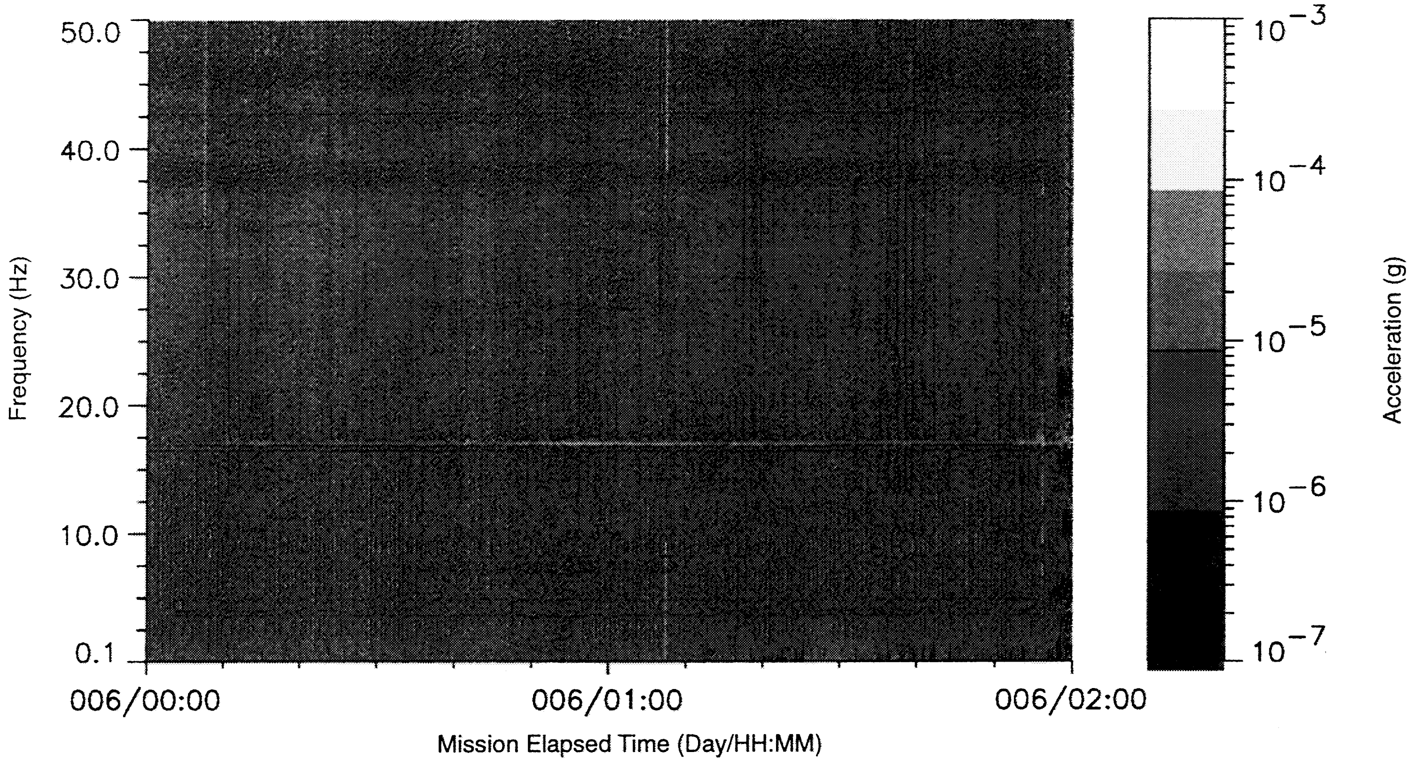

Figure C-66 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

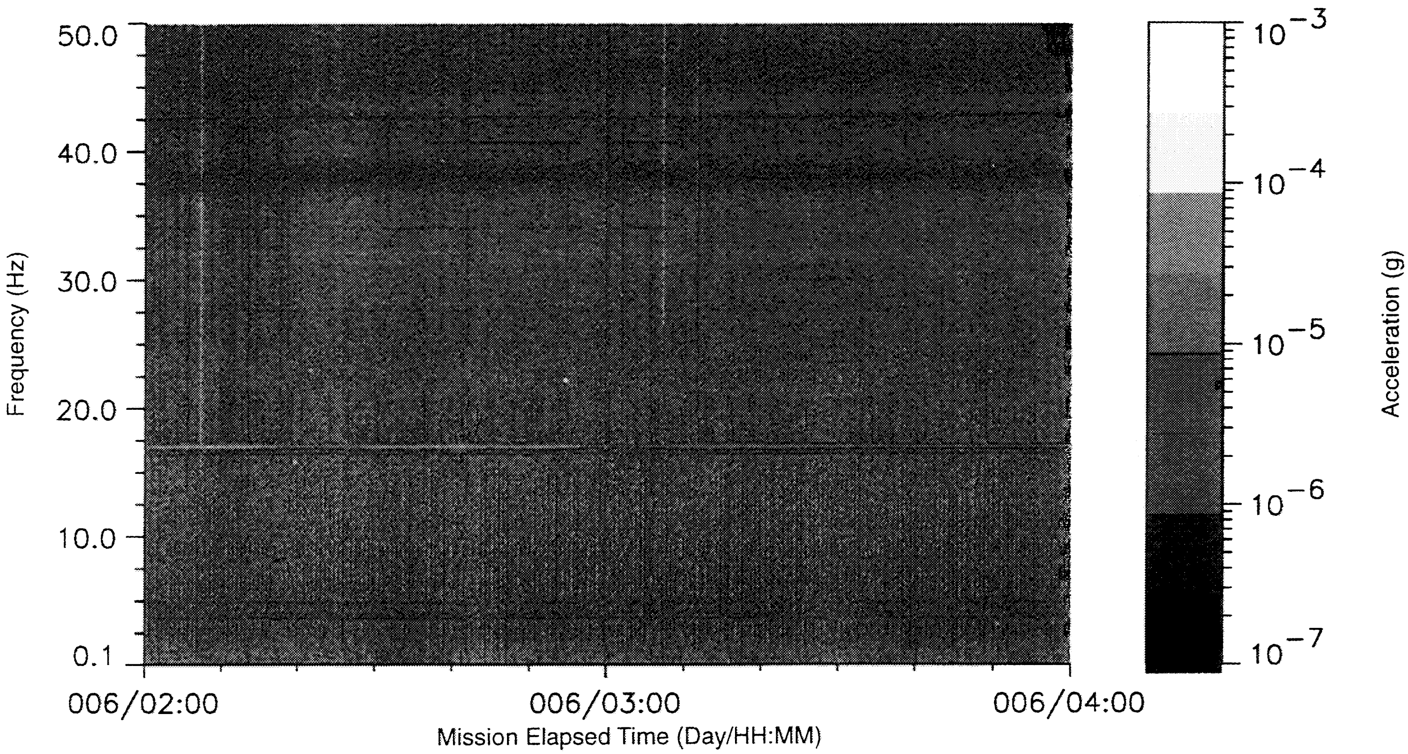

Figure C-67 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

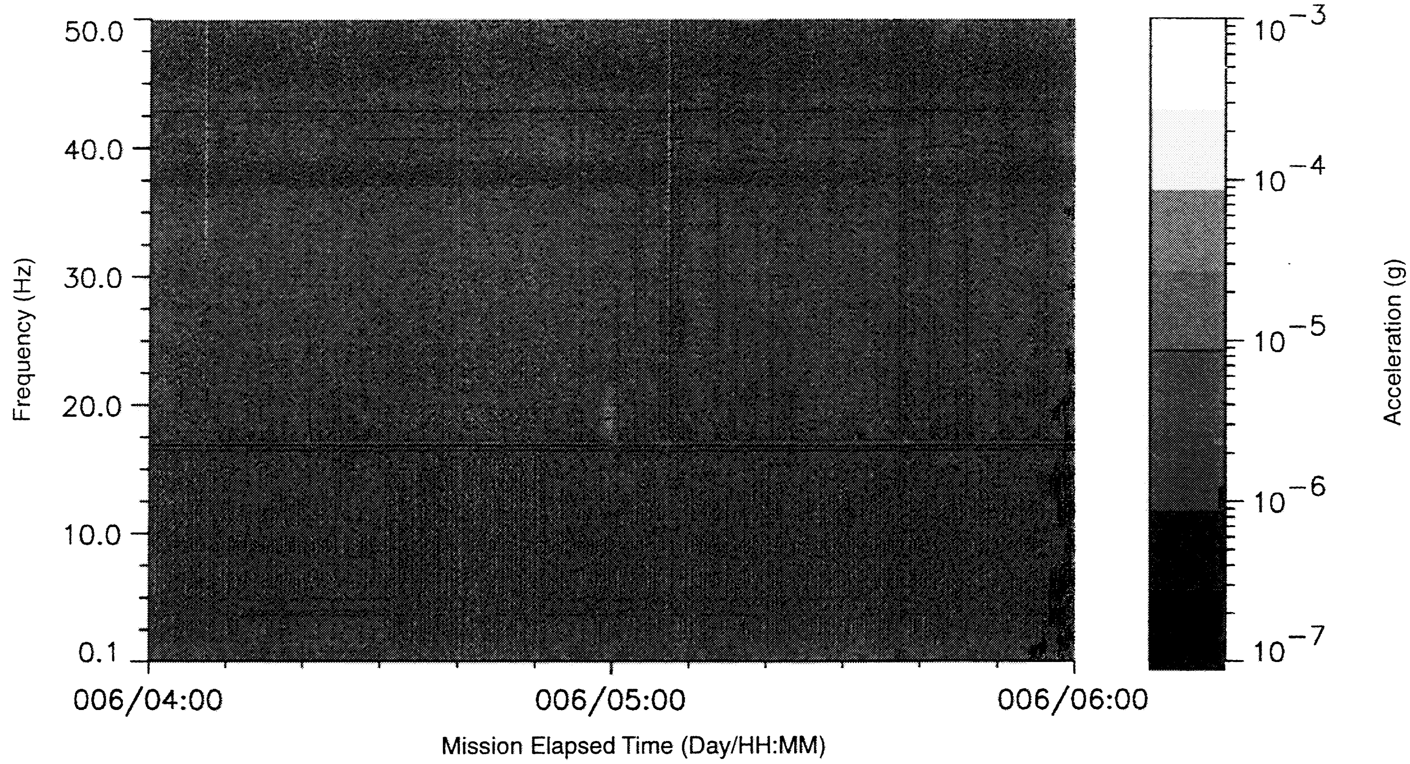

Figure C-68 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

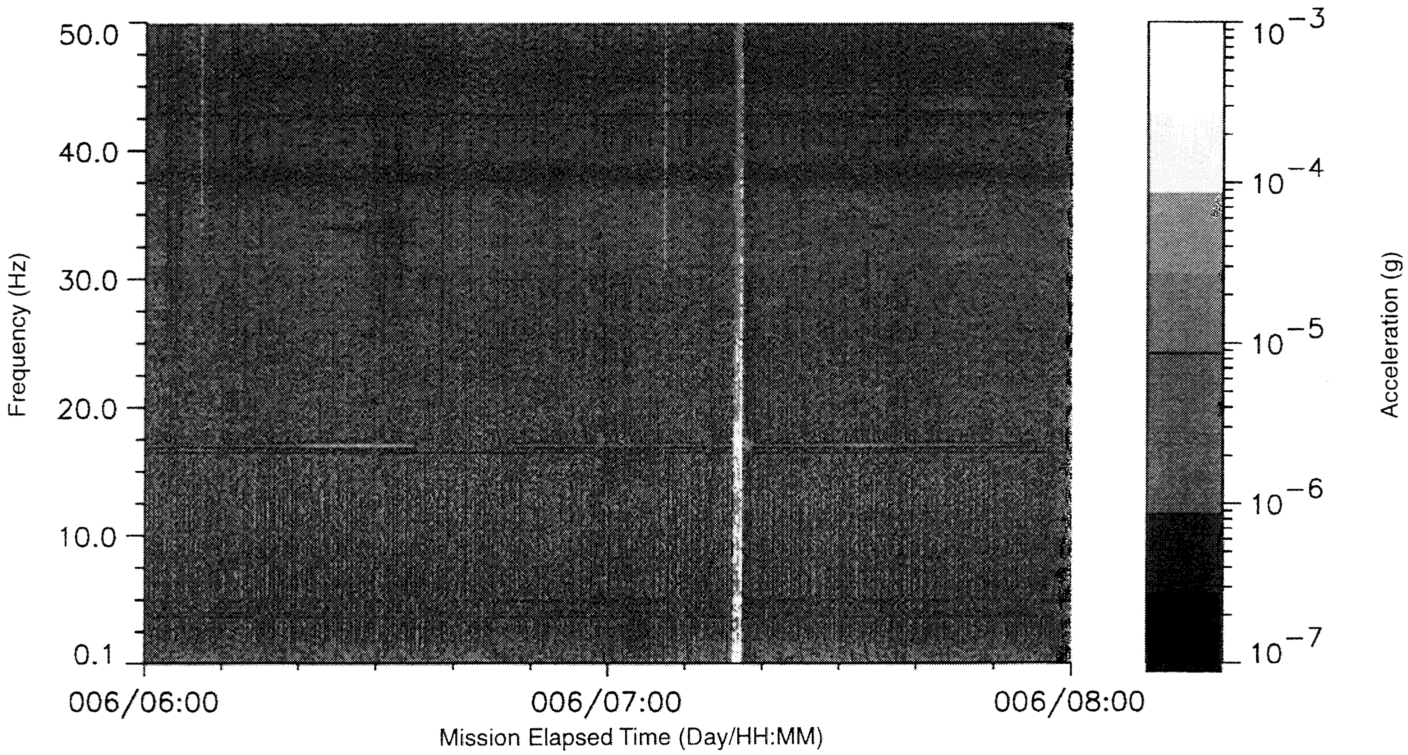

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Figure C-69 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

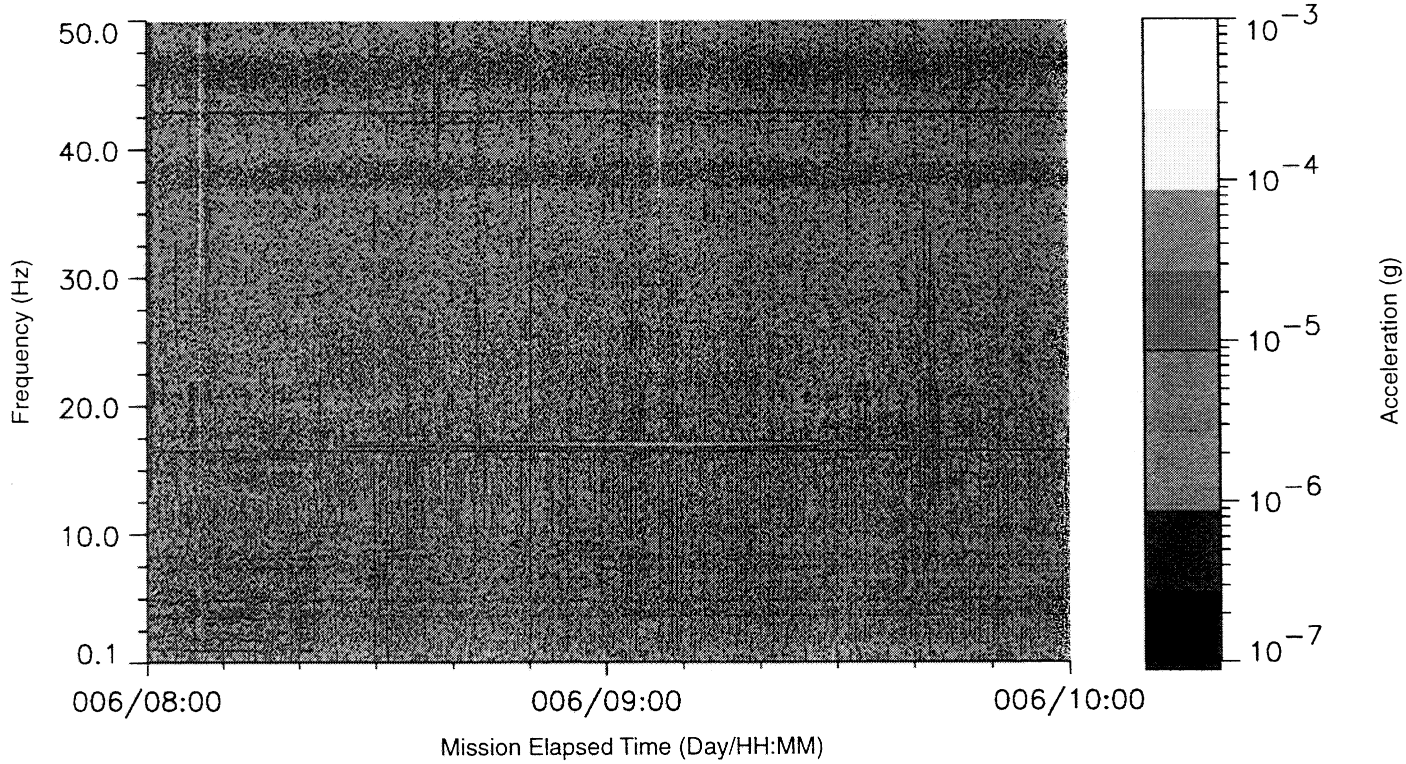

Figure C-70 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

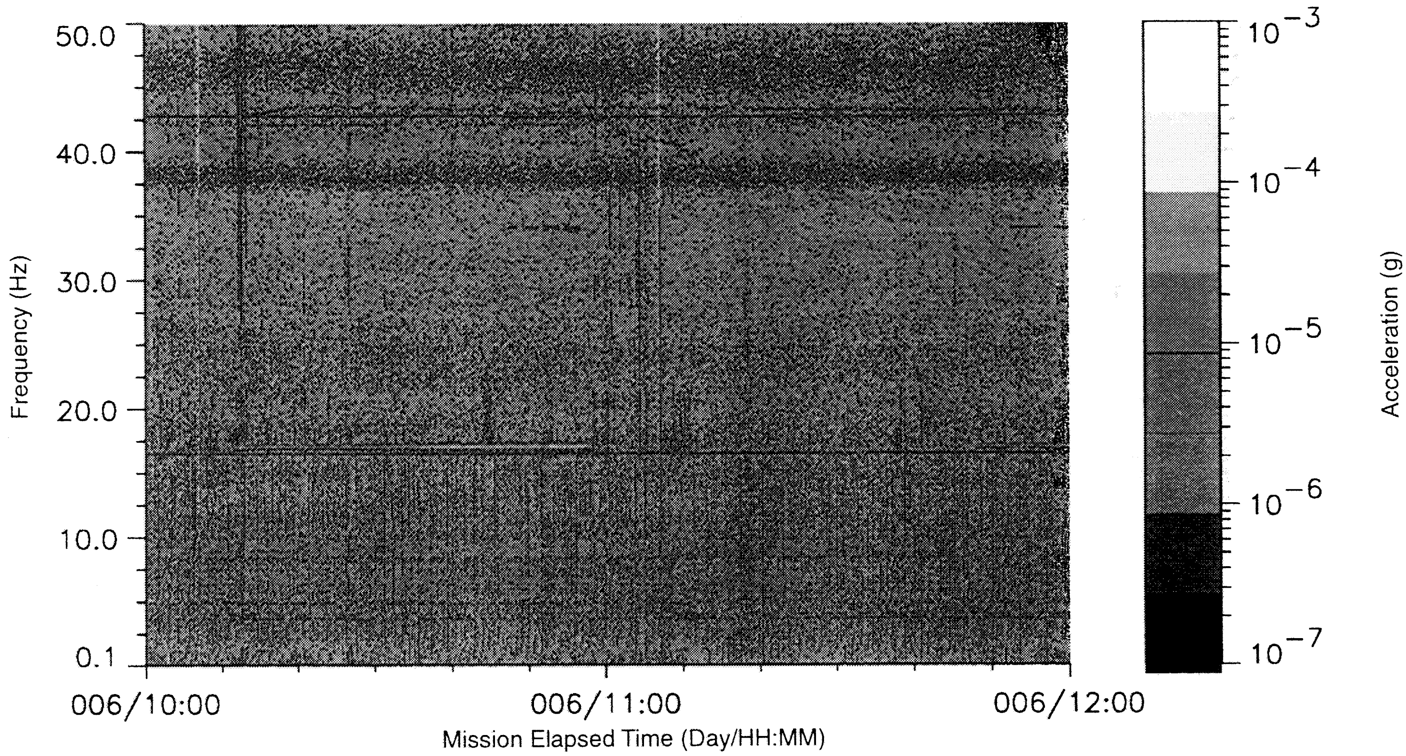

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Figure C-71 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

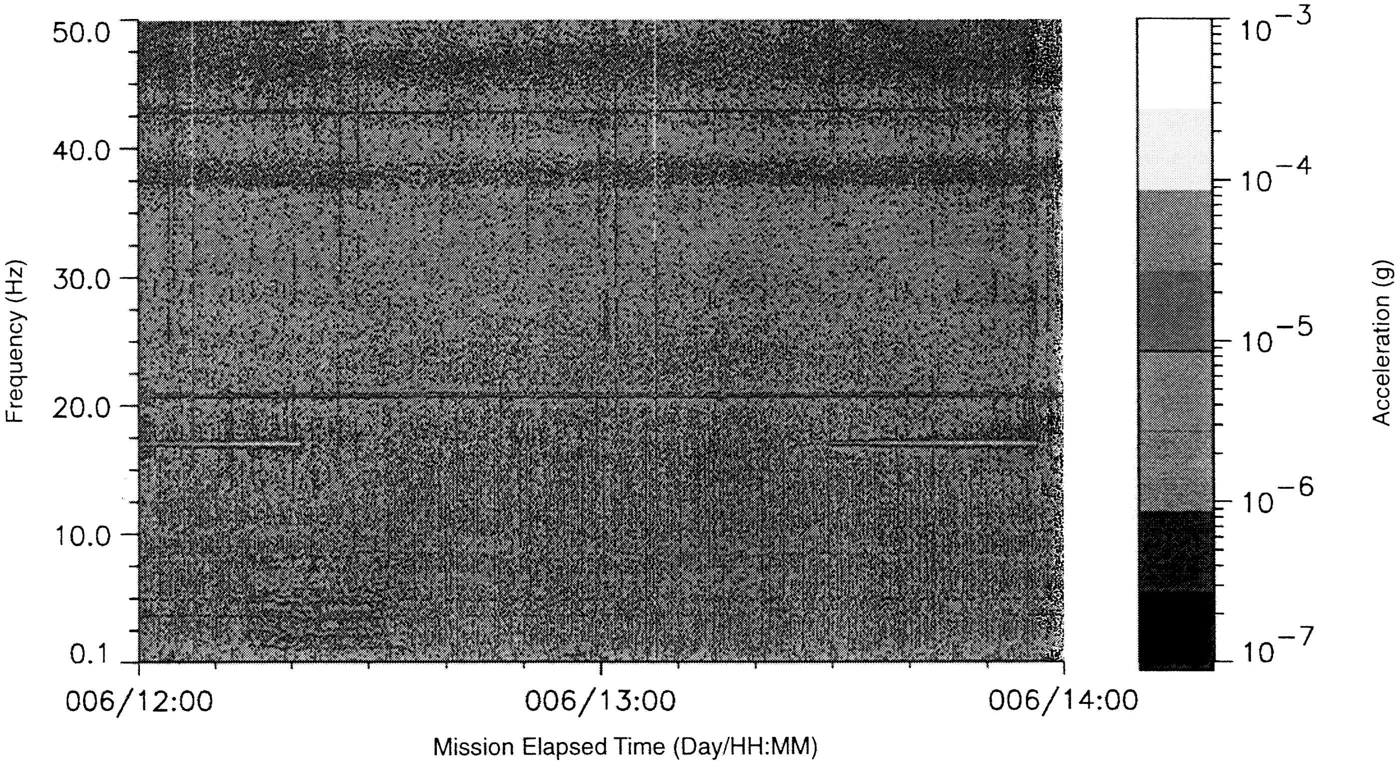

Figure C-72 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

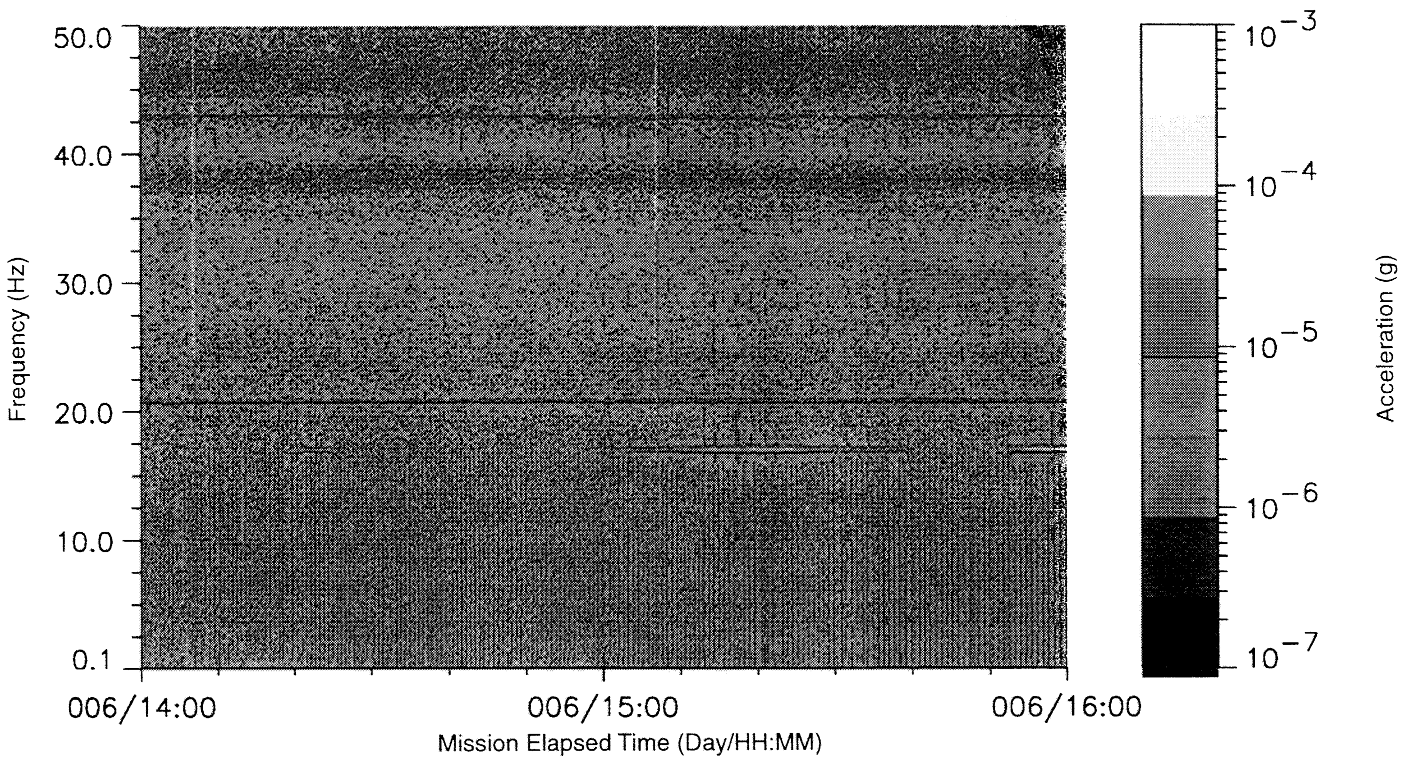

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Figure C-73 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

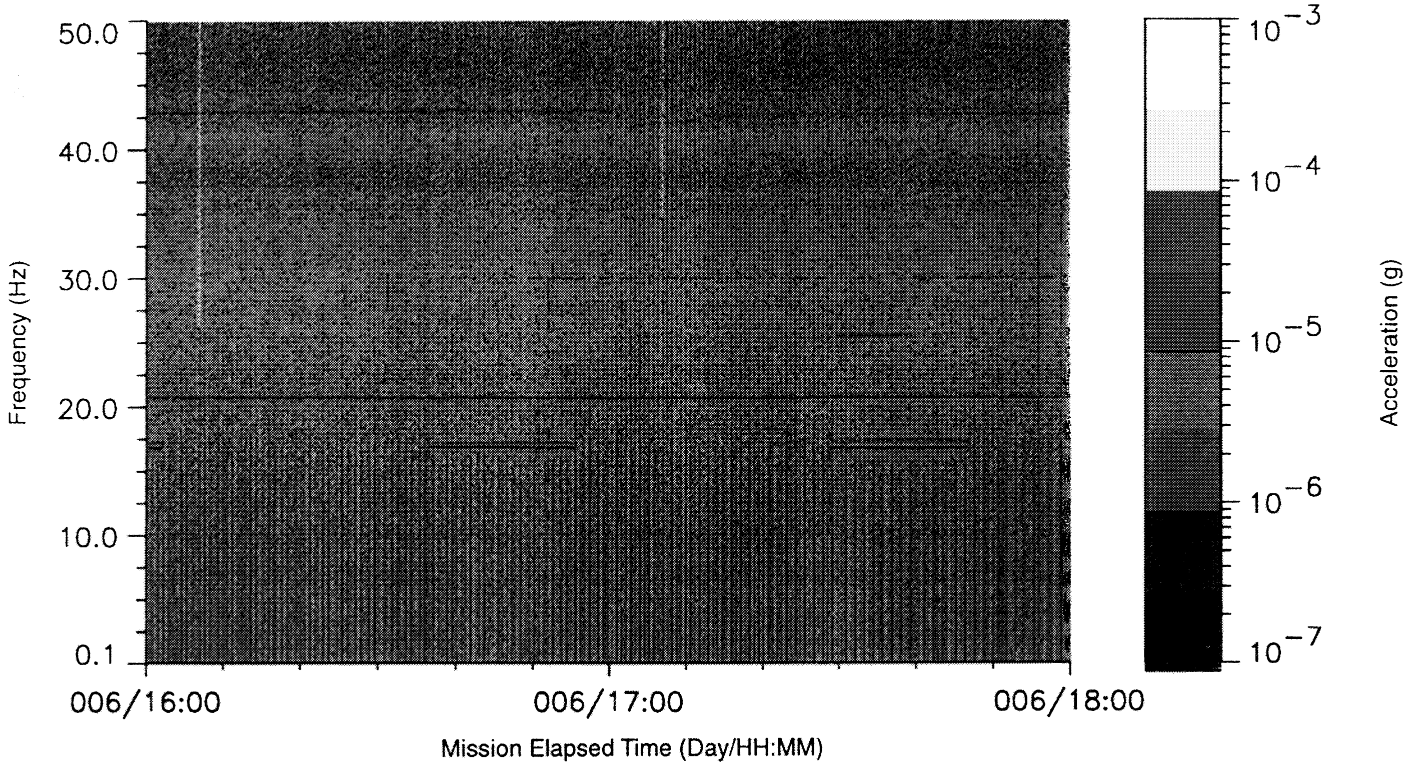

Figure C-74 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

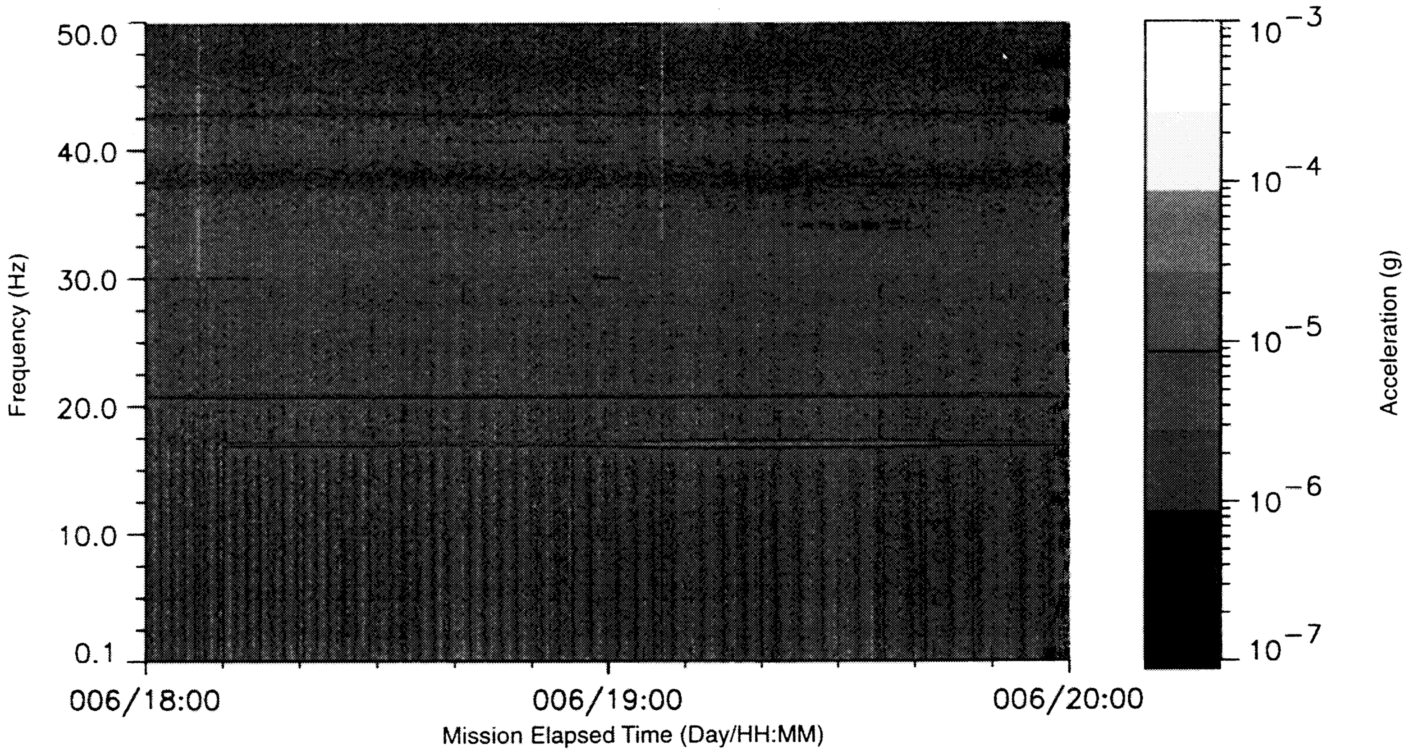

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Figure C-75 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

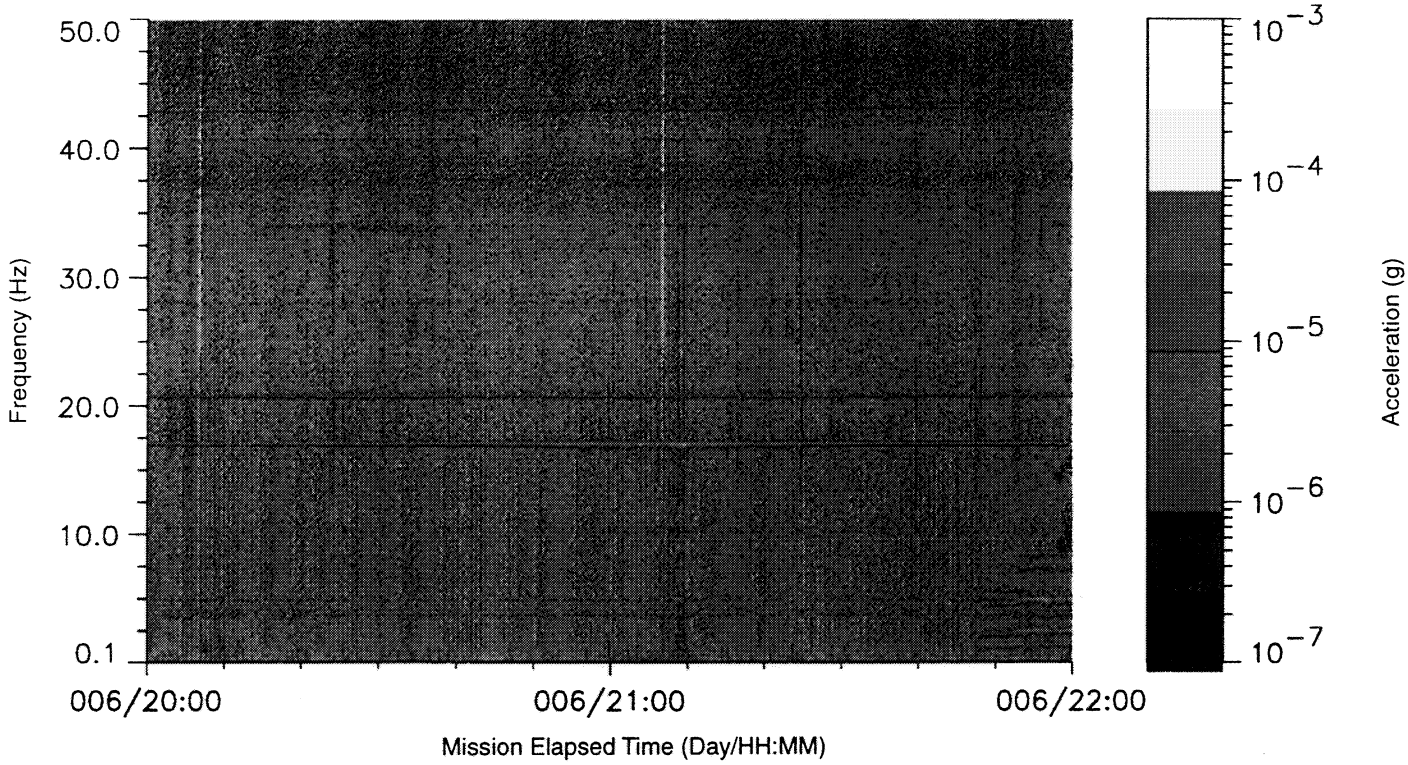

Figure C-76 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

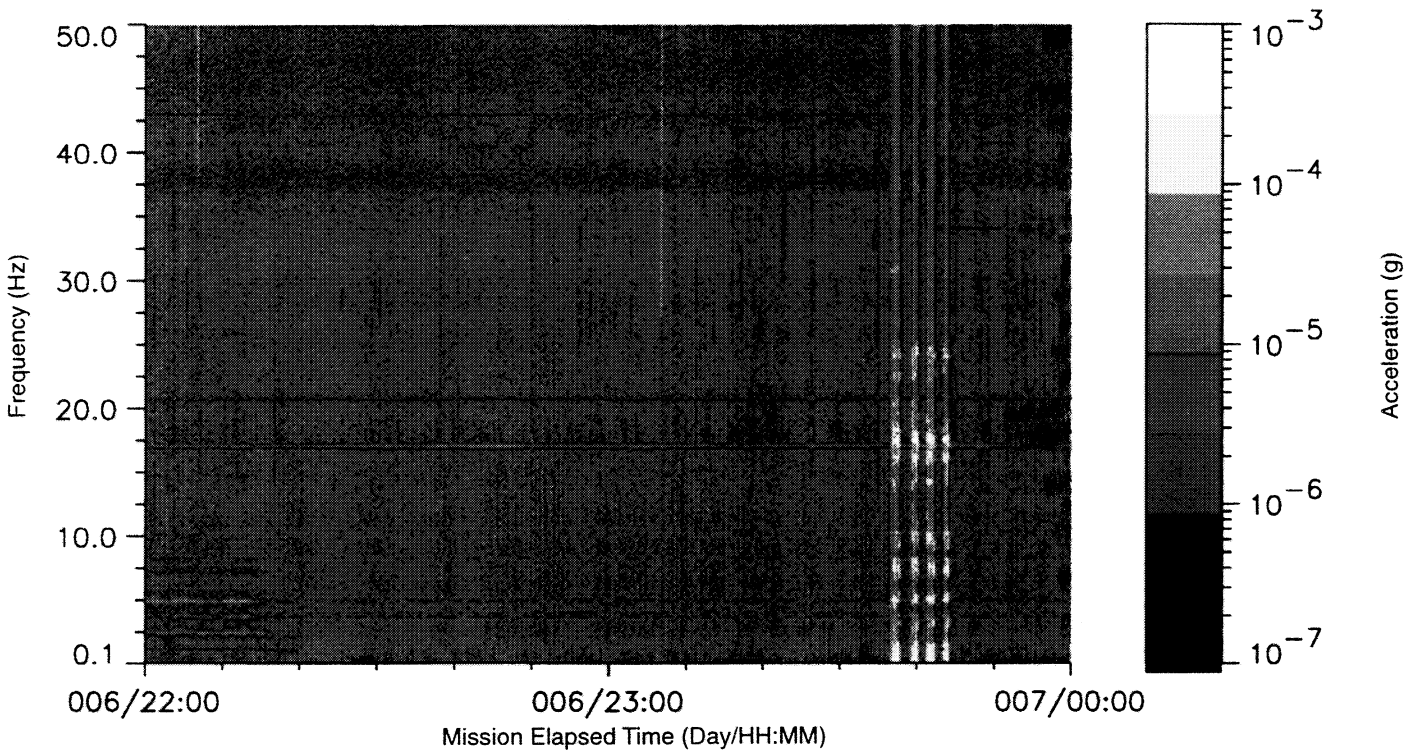

Figure C-77 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

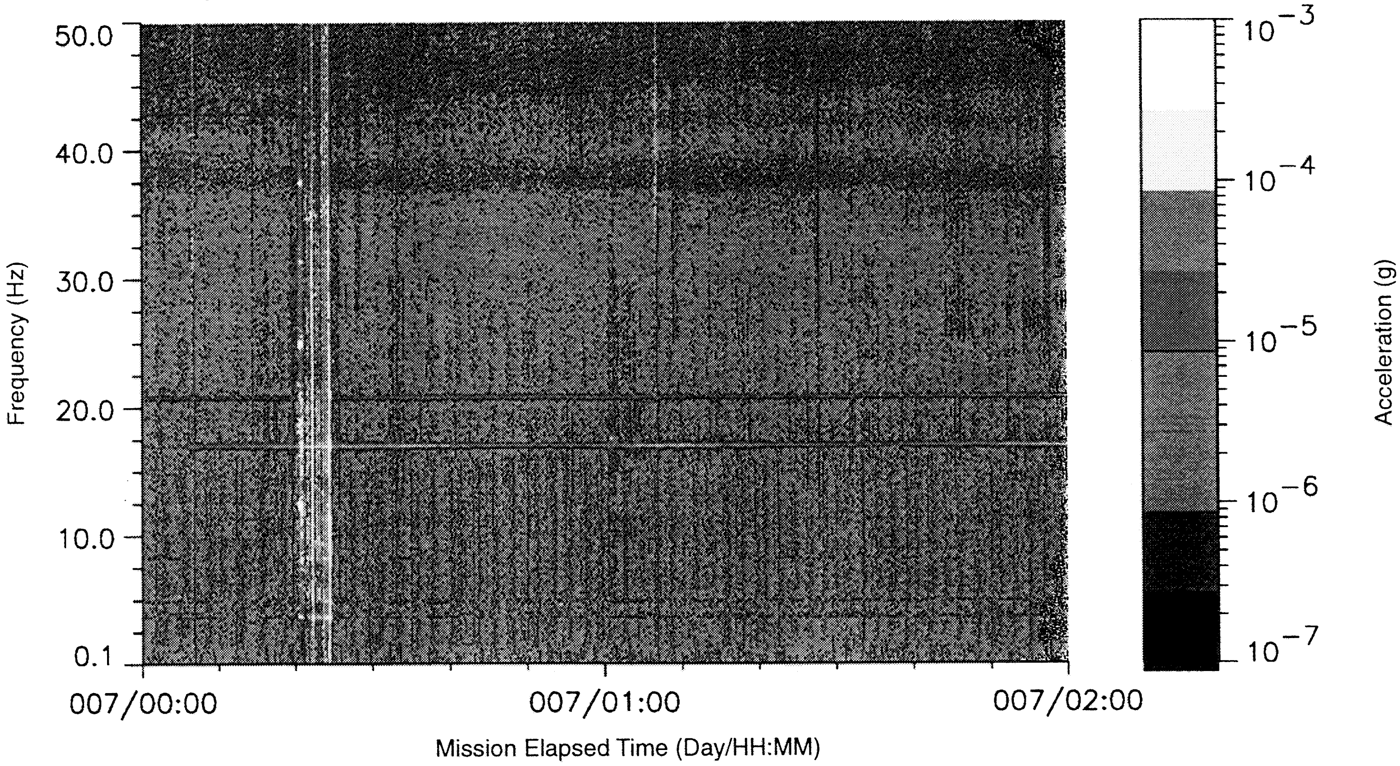

Figure C-78 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

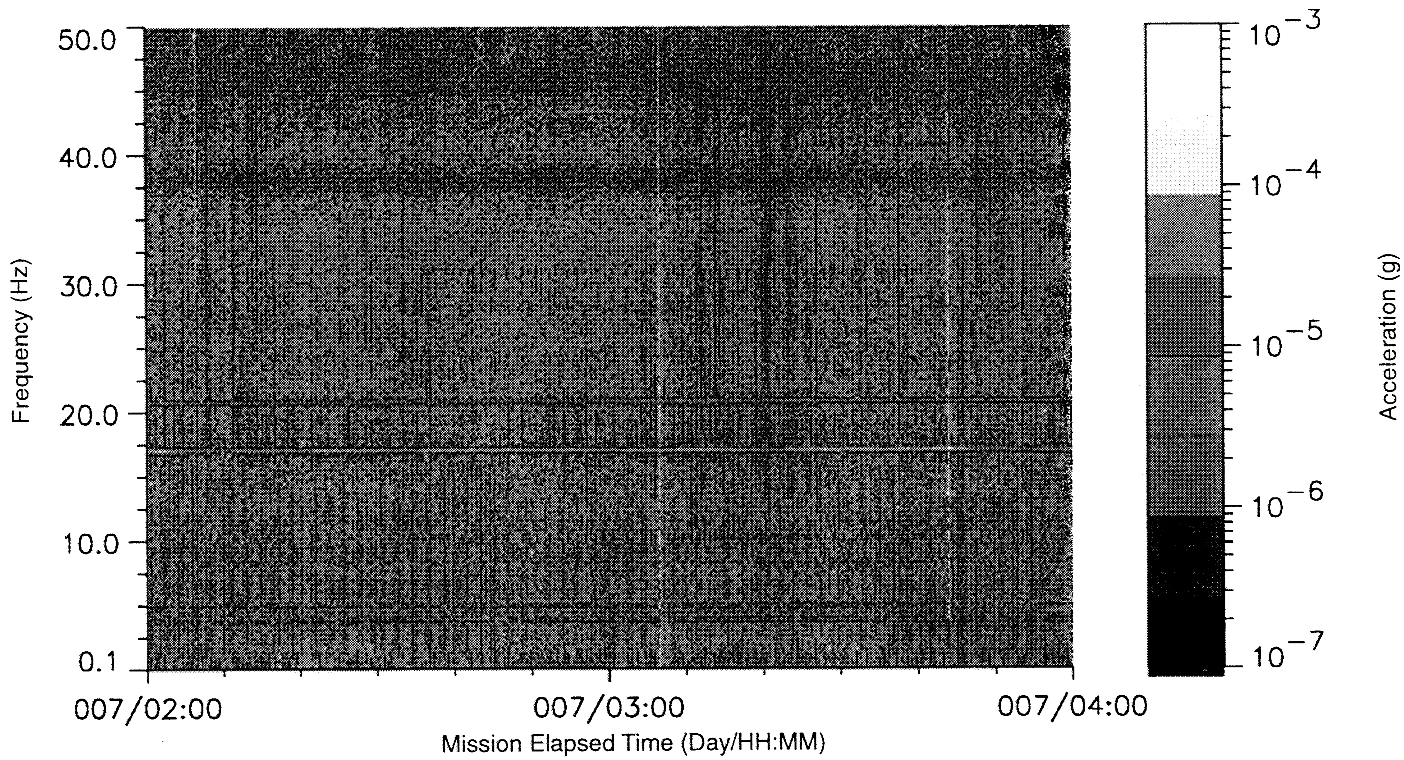

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Figure C-79 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

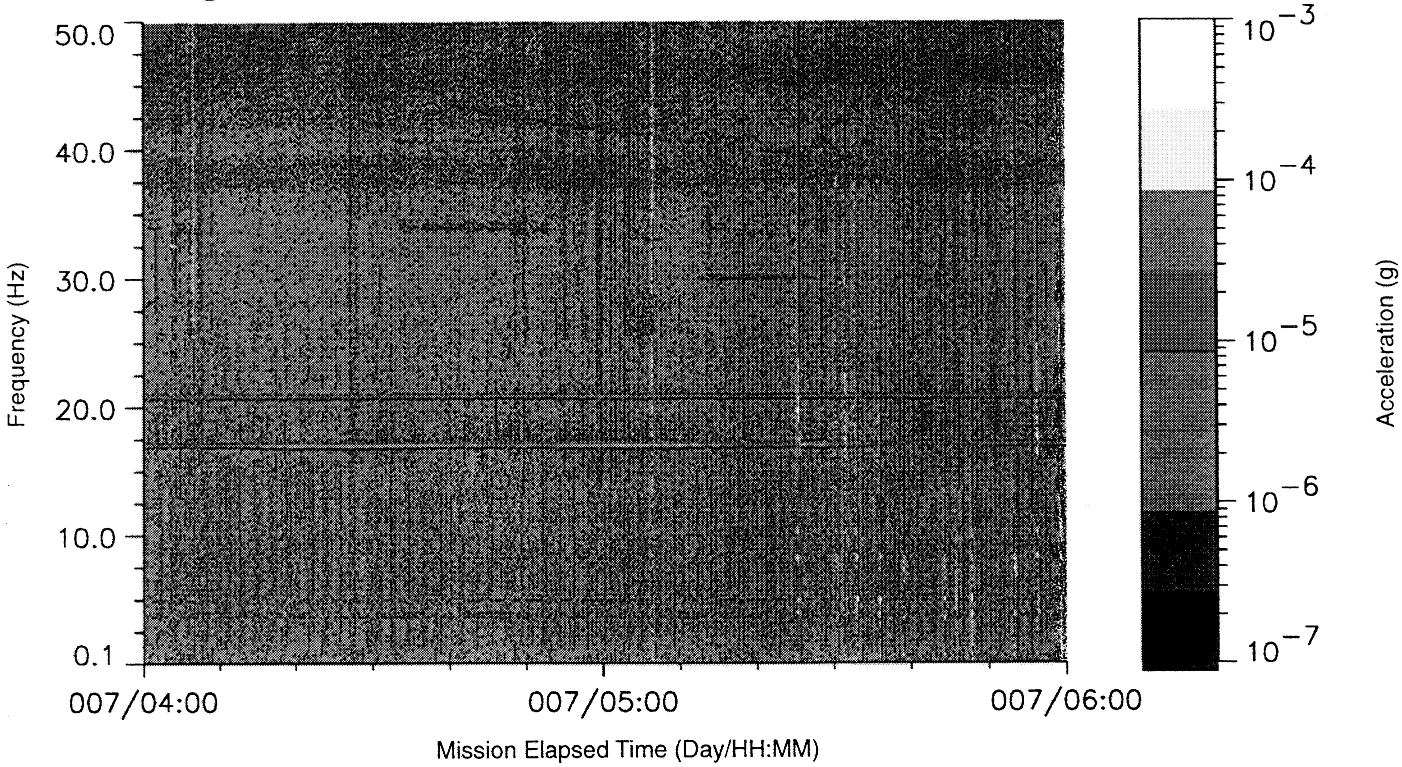

Figure C-80 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

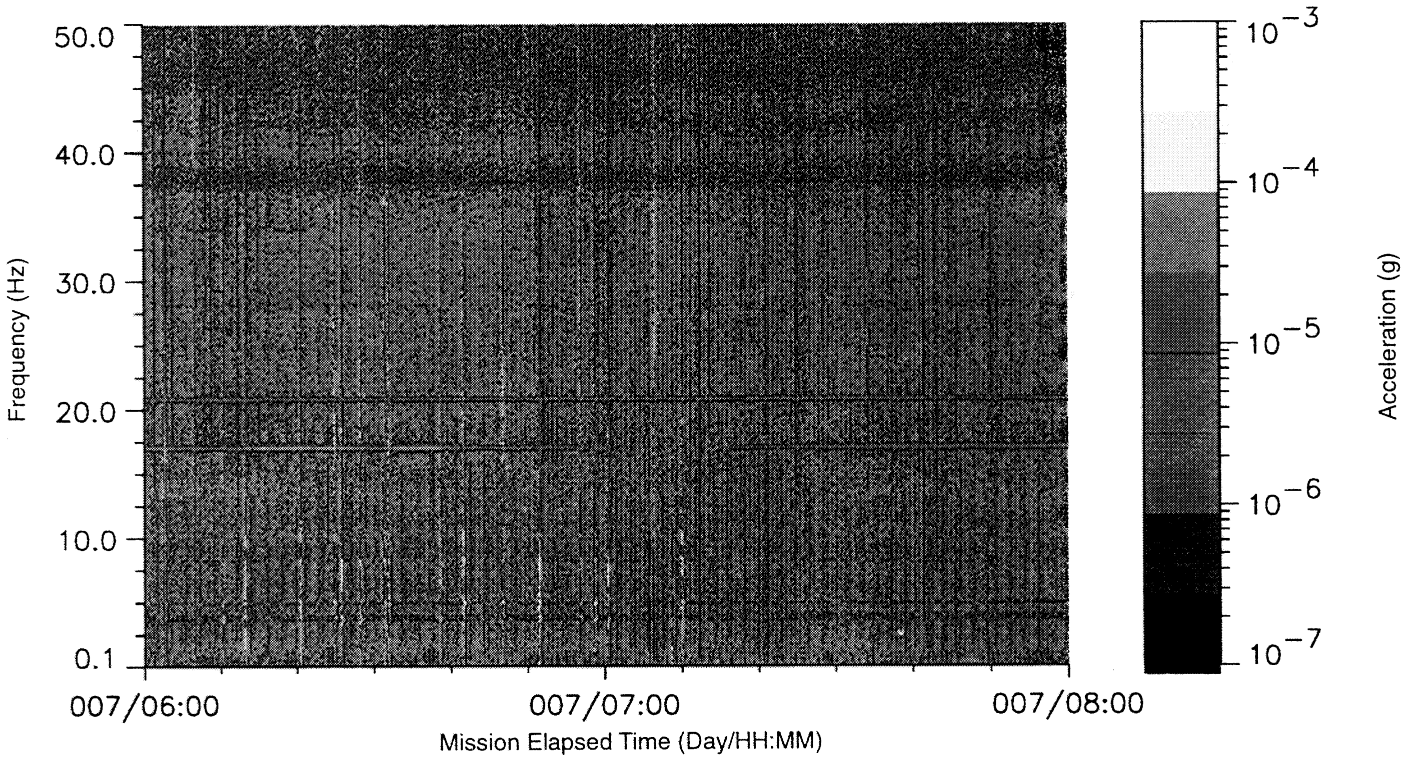

Figure C-81 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

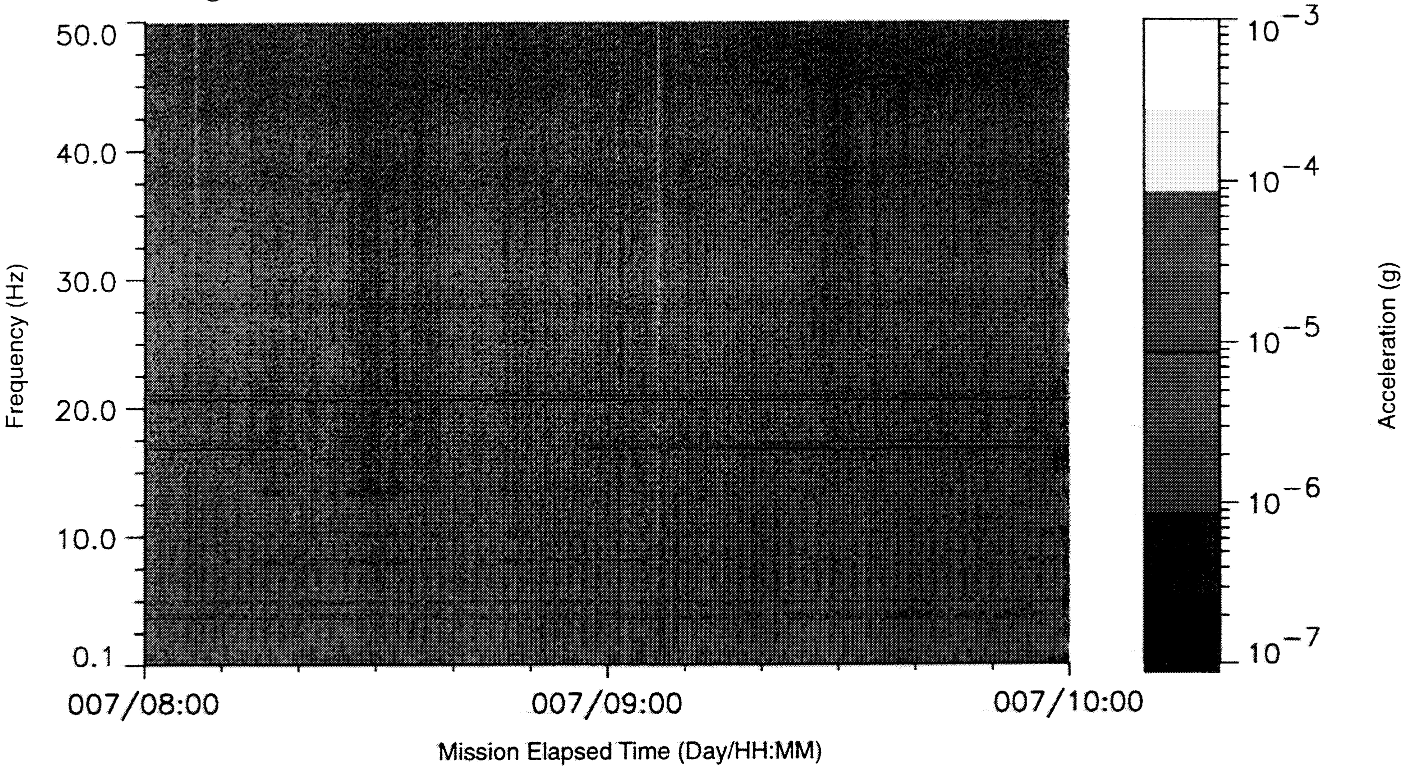

Figure C-82 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

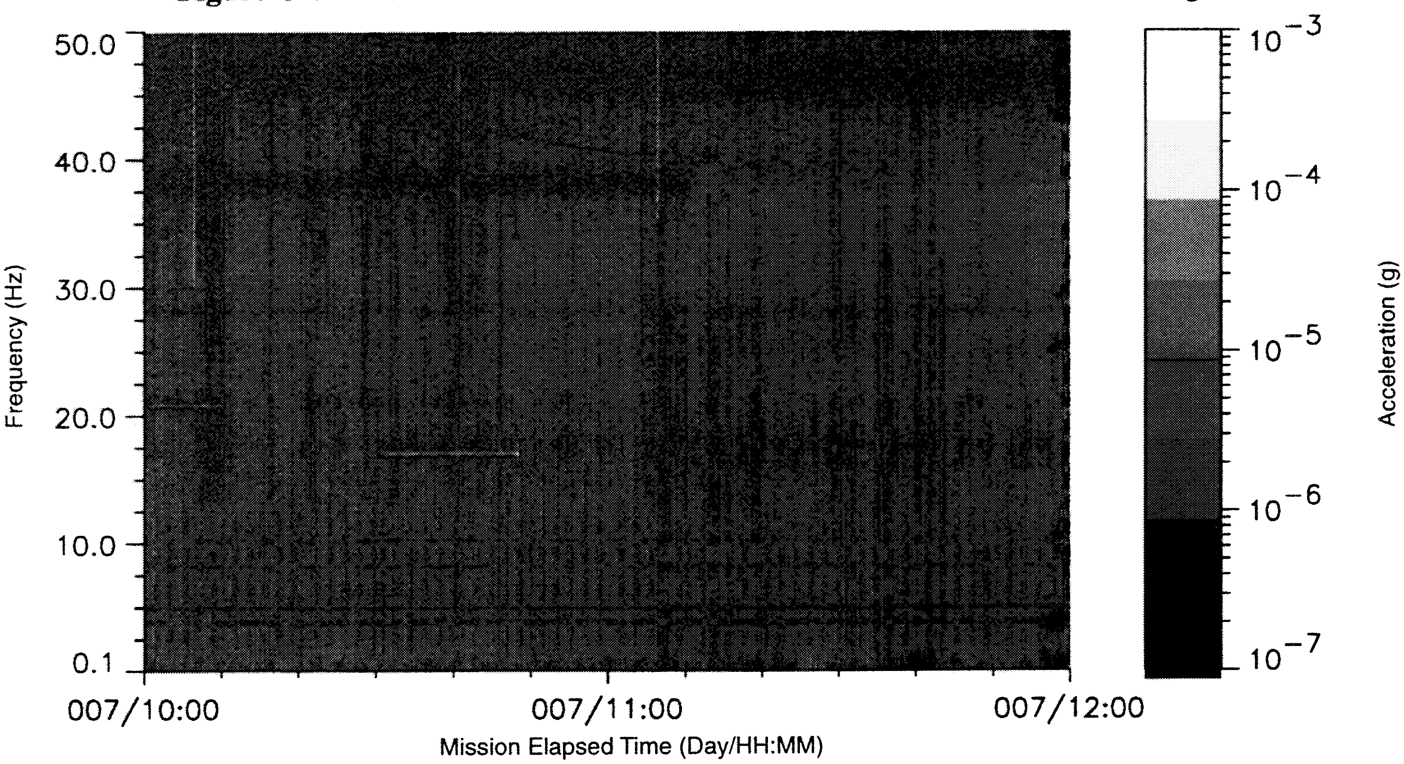

Figure C-83 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

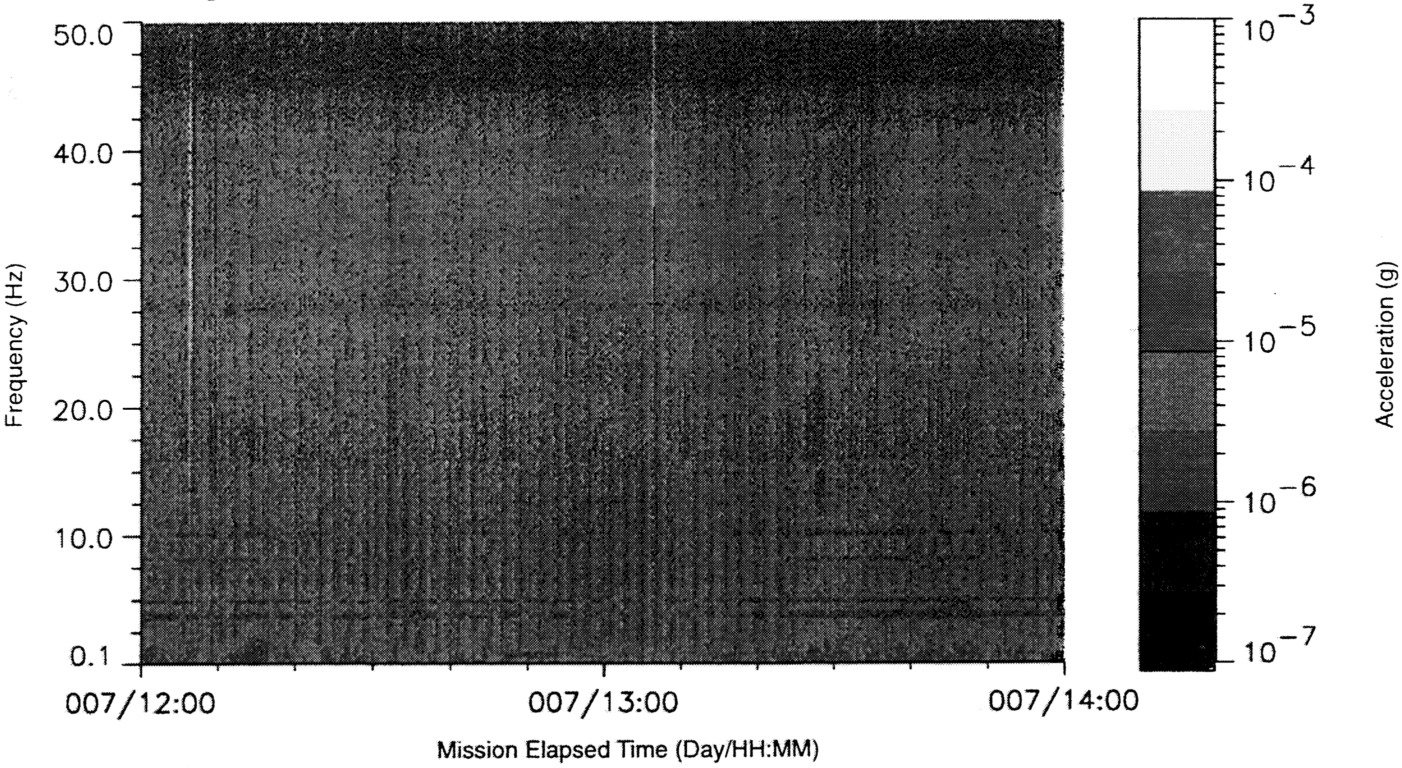

Figure C-84 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

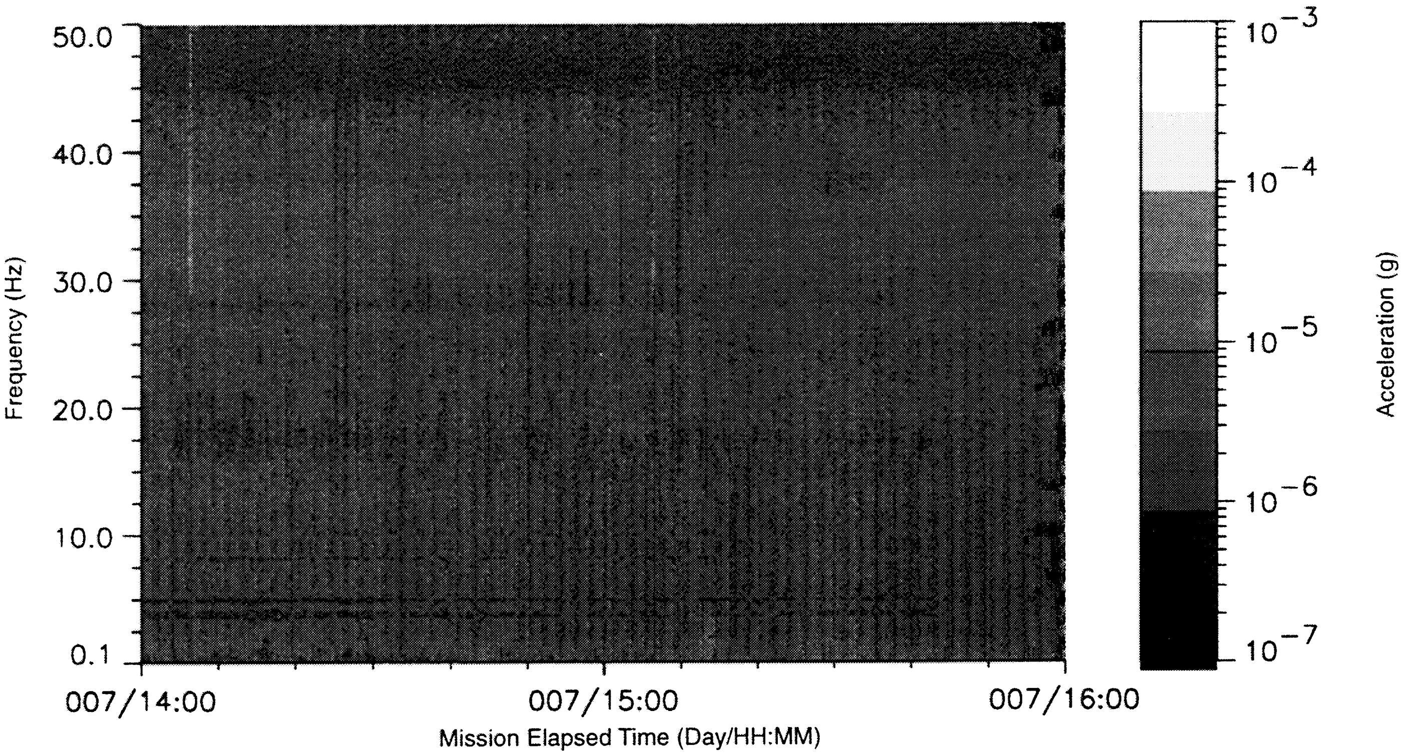

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Figure C-85 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

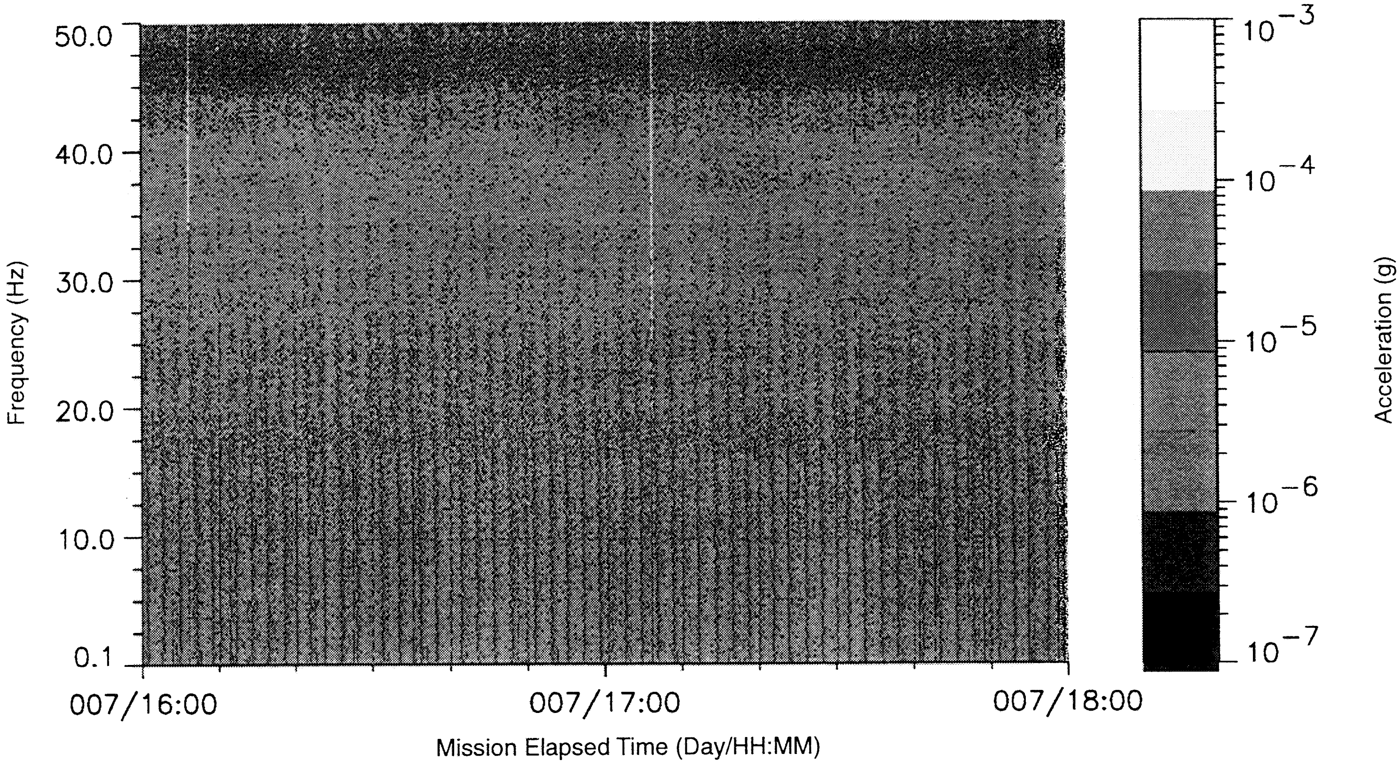

Figure C-86 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude

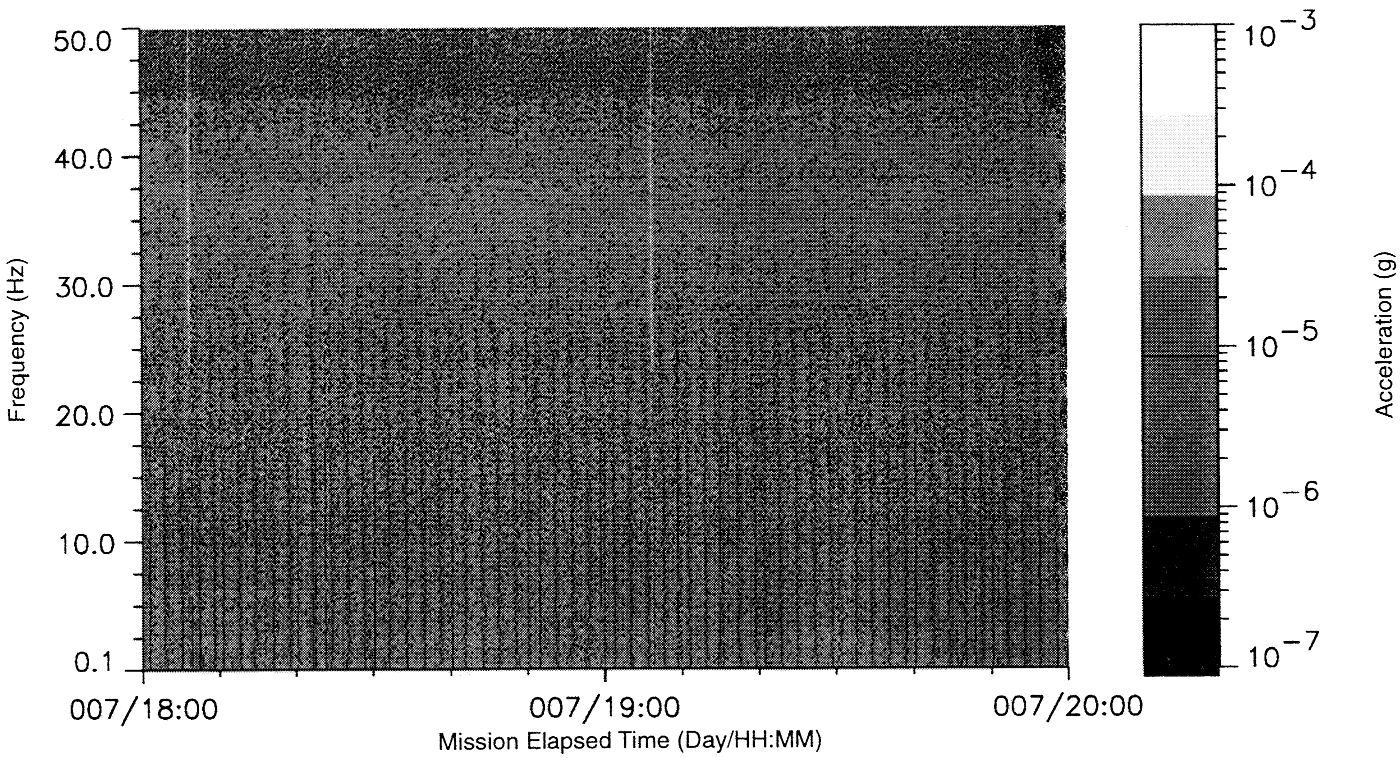

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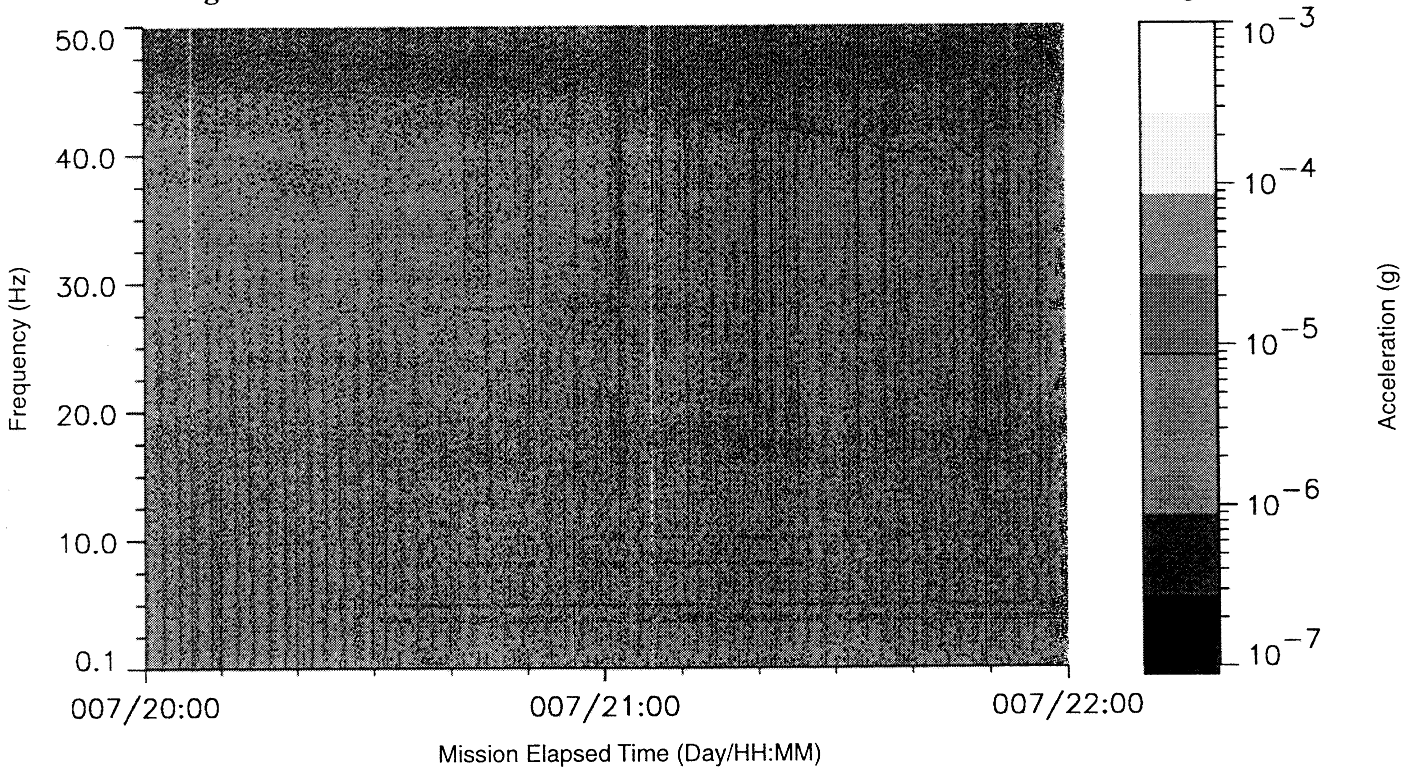
Figure C-87 SPACEHAB-2 Forward Bulkhead Starboard T-Beam, Vector Magnitude



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APPENDIX D USER COMMENTS SHEET

We would like you to give us some feedback so that we may improve the Mission Summary Reports. Please answer the following questions and give us your comments.

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2. Is there additional information which you feel should be included in the Mission Summary Reports? ______Yes ______No If so what is it?

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13. ABSTRACT ***(Maximum 200 words)***

The STS–60 mission, which launched on 11 February 1994, carried seven accelerometer systems. This report describes the configuration of each of these systems, where they were located on the Orbiter and the name of a contact person for each system. The Space Acceleration Measurement System (SAMS) was one of the accelerometer systems on-board and this mission marked its eighth successful flight. Acceleration data are provided here for SAMS which flew under an agreement between the NASA Microgravity Science and Applications Division and the NASA Office of Advanced Concepts and Technology. Acceleration data for the other accelerometer systems are not presented here. SAMS was located in the commercial SPACEHAB laboratory, on its second flight. The SAMS system was configured with three triaxial sensor heads with filter cut-offs of 5, 10 and 50 Hz. The acceleration environment related to an experiment centrifuge, an experiment refrigerator freezer unit, a SAMS sensor head rotation, an Orbiter shudder, and payload deploy activities are discussed. In the Appendices, all of the data from SAMS Head B (10 Hz) are plotted to provide an overview of the environment during the majority of the STS–60 mission. An evaluation form is included at the end of the report to solicit users' comments about the usefulness of this series of reports.

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